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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE TEMPERATURE COEFFICIENT OF THE POTENTIAL OF THE CALOMEL ELECTRODE, WITH SEVERAL DIFFERENT SUPERNATANT ELECTROLYTES.

By Theodore William Richards.

Investigations on Light and Heat, made and published wholly or in part with Appropriation from the Rumford Fund.

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By Theodore William Richards.

Presented May 12, 1897. Received May 18, 1897.

The well known Gibbs-Helmholtz formula for the temperature coefficient of a galvanic cell has been often tested,* with results which have usually been confirmatory. In 1885, however, among a number of satisfactory experiments, Gockel obtained a series of results † which he was at a loss to explain. He measured the temperature coefficient of calomel electrodes containing various supernatant electrolytes by setting up cells of the general form $Hg–HgCl–MCl_n–HgCl–Hg$, and maintaining the two ends at different temperatures. His results were as follows, each of the solutions being of half normal strength.

Gockel's Results.

Cell.	Temperature Coefficient.
$Hg - HgCl - ZnCl_2 - HgCl - Hg$	+0.000675
$Hg - HgCl - CdCl_2 - HgCl - Hg$	+0.000680
$Hg - HgCl - BaCl_2 - HgCl - Hg$	+0.000440
$Hg - HgCl - SrCl_2 - HgCl - Hg$	+0.000287
$Hg - HgCl - NaCl - HgCl - Hg$	+0.000119

These variations are not easily explicable. It is manifest that the usual equation for the temperature coefficient of a galvanic cell involving univalent ions — $\frac{d\pi}{dT} = \frac{\pi}{T} - \frac{Q}{\epsilon_0 T}$, in which π represents the potential, T the absolute temperature, Q the total change of energy (the heat of the reaction), and ϵ_0 the quantity of electricity — does not directly apply in its present form. This equation is intended to represent the temperature coefficient of a complete cell, while we are considering that of a single electrode. In the cell Hg–HgCl–KCl–HgCl–Hg the quantity dQ, which is neglected in the evolution of the above formula, may be an important factor; it is manifest that, since the two ends are alike, this quantity must represent the only difference between the heats of reaction at the hot and cold ends.

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* Czapski, Wied. Ann., Vol. XXI. p. 239 (1884); Jahn, Wied. Ann., Vol. XXIV. pp. 21, 491 (1886); Loven, Z. Phys. Chem., Vol. XX. p. 456; Bugarszky, Z. Anorg. Chem., Vol. XIV. p. 145; and others.

† Wied. Ann., Vol. XXIV. p. 618; table on p. 638.

We might nevertheless expect the change of electromotive force with the temperature of a single electrode to be in general affected by the same factors as that of a cell; in other words, to be independent of every affecting cause but the potential, the absolute temperature, and the relation of the change of total energy to the quantity of electricity. We should expect the nature of the kation in the surrounding solution to have no direct influence, and hence the very large discrepancies observed by Gockel remain without explanation. The matter seemed worth investigation, and two years ago the present work was begun.

In the first place, many crude experiments were made for the purpose of orientation. These determinations were little more than a repetition of Gockel's, with the addition of a few with more dilute solutions, and the substance of them is presented in the first table below. Each of the figures is the average of a number of experiments, which agreed reasonably well with one another. Some of these experiments were made by Mr. Harold Edwards, to whom I would here express my thanks.

SERIES I.

PRELIMINARY.

Temperature 20°–55°.

	Half normal.	Twentieth normal.	Fiftieth normal.
Hydric chloride	0.00030		
Sodic chloride	0.00062	.0008	.0009
Potassic chloride	0.00062	. . . . . .	.0009
Zincic chloride	0.00066		
Baric chloride	0.00059		

These results differ materially from Gockel's, which remain incomprehensible, but the irregularities are still sufficiently marked, especially in the case of the hydrochloric acid, to warrant further investigation. But the exigencies of a research of this sort, the necessity of a large number of pure materials, and the long duration of each experiment, postponed the completion of the work for a much longer time than had been anticipated.

First, a word about the materials employed in the work which follows. The mercury was carefully purified chemically, and was also distilled in a vacuum. Four grades of mercurous chloride were used; in the first crude experiments "pure" calomel of commerce sufficed; subsequently a new portion of the salt was precipitated from an exceedingly dilute solution of mercurous nitrate, which was free from every impurity except mercuric nitrate, by the addition of hydrochloric acid; the third sample was made in this same way from very carefully prepared mercurous nitrate which had long been digested with mercury; and this third sample upon being twice successively sublimed yielded the fourth. When sufficiently washed with successive portions of a decinormal solution of potassic chloride, each of these preparations yielded "decinormal electrodes" of precisely the same potential, showing that as far as this work was concerned they were all alike. For most of the work the third sample, as being at the same time convenient and trustworthy, was adopted.

In order to free the hydrochloric acid which was used from possible traces of bromine and iodine, it was somewhat diluted and twice treated with a few crystals of potassic permanganate, each time boiling until all the chlorine was expelled. The acid was then twice successively distilled in a retort provided with a platinum condenser, rejecting the first and last portions of the distillate.

The soluble chlorides were also of a high grade of purity. Many had been prepared in the course of recent atomic weight determinations in this laboratory, and were far purer than is required in an investigation of the present sort, while others were prepared for this research. Especial pains were taken to exclude all anions except chlorine. The solutions were always made in such a way as to be as neutral as possible; they were in the first place prepared of the desired strength, and this strength was subsequently verified by a determination of the chlorine according to a modification of Volhard's method proposed independently by Sanger * and myself.† Although parallel experiments with boiled and unboiled solutions showed no difference in the temperature coefficient, the solutions were usually boiled for a short time in Jena glass vessels to expel most of the air. It soon appeared that the most serious cause of irregularity con-

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[*] These Proceedings, XXVI. 34.

[†] These Proceedings, XXIX. 67.

sisted in accidental traces of water adhering to glass or mercury, which had the effect of unequally diluting the electrolyte in the cell, and thus causing concentration currents. If the apparatus is dried and the mercurous chloride is carefully washed with the appropriate solution before being added, the ease with which one may obtain consistent results is quite remarkable. The water used in these experiments, except in the first crude ones, was ordinary distilled water which had been redistilled from alkaline permanganate in a platinum still.

The first systematic experiments had for their aim the determination of the probable magnitude of the errors of observation due to accidental causes.

The apparatus consisted of two test tubes mounted in a convenient rack, in such a way that the liquid contents could be connected by a syphon. This tube could be filled by suction through a third arm above. Each test tube contained a few cubic centimeters of mercury, and above this mercury was placed a layer of finely divided mercurous chloride, surrounded by the electrolyte which filled the rest of the apparatus. If the layer was left undisturbed, its thickness was found to be unessential.

The two test tubes were kept at different temperatures by means of suitable baths of constant temperature, a steam jacket being employed for 100°, and pure cracked ice for 0°. At first the readings of the external thermometers were verified by means of very small accurate Anschütz thermometers placed in the test tubes themselves; but after many such verifications, which always resulted satisfactorily, this practice was discontinued, and the readings of the external thermometers alone were taken.

The differences of potential between the two layers of mercury were measured by the well known Ostwald-Poggendorff method,* within perhaps 0.0002 volt. The final reading was not taken until the temperature conditions had thoroughly adjusted themselves, an operation requiring from half an hour to many hours, according to circumstances.

In the first place a series of determinations of the effect of dilution upon the temperature coefficient of the electrode containing supernatant hydrochloric acid was made. The stronger solutions gave very uncertain results, and hence cannot be considered accurately determined; and correspondingly, in these the calomel was partially decomposed with separation of finely divided mercury. The reasons for these irregularities were better understood later.

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* Hand- und Hilfsbuch phys. chem. Mess., pp. 251–255.

SERIES II.

THE EFFECT OF DILUTION.

Hg — HgCl — (HCl of varying strength) — HgCl — Hg.

Strength of Solution.	Temperature Coefficient between 20°-100°.
Twice normal	+0.000150 (?)
Normal	+0.000210 (?)
Half normal	+0.000250 (?)
Fifth normal	+0.000285
Tenth normal	+0.000324
Twenty-fifth normal	+0.000394
Fiftieth normal	+0.000438

It is evident that the temperature coefficient increases rapidly with dilution, as had already appeared from Series I. It is important, therefore, to adjust carefully the strength of the solutions to be used.

The effect of impurities and of mixing solutions was the next point to be tested. This effect could naturally be observed most satisfactorily by measuring cells containing mixtures of two electrolytes giving widely different temperature coefficients when pure; hence the third series of results, for which potassic and hydric chlorides were used.

SERIES III.

THE EFFECT OF MIXED SOLUTIONS (HALF NORMAL).

Hg — HgCl — (KCl + HCl) — HgCl — Hg.

Per Cent of Potassic Chloride Solution.	Per Cent of Hydrochloric Acid Solution.	Temperature Coefficient between 20° and 100°.
100	0	.00059
90	10	.00053
82	18	.00048
75	25	.00043 (?)
50	50	.00035
25	75	.00030
0	100	.00025

From these figures it is evident that small amounts of impurities can cause but slight differences in the result. The curve of changing temperature coefficient is a regular and gradual one.

The next series of results had for its object the determination of the effect of changing temperature. Heat evidently assisted the decomposition of mercurous chloride, for the precipitate in the warmer tube had always appeared the grayer of the two. Upon cooling to the same temperature, however, the potential always came back to zero, unless evaporation had been allowed to make one solution more concentrated than the other. Experiments in which the potential did not return to zero were rejected.

SERIES IV.

CHANGE OF TEMPERATURE COEFFICIENT WITH CHANGE OF TEMPERATURE.

Range of Temperature.	Temperature Coefficient. Hydrochloric Acid $\frac{n}{2}$. Hg — HgCl — HCl — HgCl — Hg.	Temperature Coefficient. Potassic Chloride $\frac{n}{2}$. Hg — HgCl — KCl — HgCl — Hg.
0° — 25°	.00037	.00067
25° — 50°	.00026	.00063
50° — 75°	.00023	.00058
75° — 100°	.00021	.00056

In the course of these experiments it had been noticed that an electrode upon shaking always yielded a higher potential than after it had remained standing. This was especially the case with concentrated solutions and high temperatures. This fact has been observed by Coggeshall,* who recommends a layer of sand or small pebbles as a means of preventing the agitation. The irregularity in question appeared to show a lack of homogeneity in the solution, and it seemed important to explain the matter before proceeding further.

With this end in view, several experiments were made with bromides instead of chlorides. Here the irregularity was found to be vastly greater, and the precipitated bromide became gray at once even in cold solutions. Normal solutions gave results which varied over the wide limits given below, and even these cannot be considered the possible limits. Decinormal solutions were much less uncertain, but these seemed to be as much affected as normal solutions of chlorides.

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* Z. Phys. Chem., XVII. 62.

SERIES V.

BROMIDES BETWEEN 0° AND 30°.

$Hg - HgBr - (MBr_n) - HgBr - Hg.$

Electrolyte = MBr_n.	Normal Solution.	Decinormal Solution.
Hydrobromic acid	.00044 to .00047	
Strontic bromide	.00061 to .00068	.00070
Zincic bromide	.00065 to .00077	.00090

It was at once evident that the cause of the difficulty was the occurrence of the following reactions: —

$$2\ HgCl^* = HgCl_2 + Hg,$$
$$2\ HgBr = HgBr_2 + Hg,$$

which seem to be effected by a "catalytic" action of the haloid ions in the solution.

This reaction has already been observed by Miahle,† but a confirmation seemed desirable. Numerous solutions decanted from the present experiments were filtered, and found by testing with stannous chloride or hydrogen sulphide to contain mercuric salts, — the normal bromides very large amounts, the normal chlorides and decinormal bromides much less, and the decinormal chlorides very little. In order to subject the method to a rigid test, a quantity of mercurous chloride was prepared with very great precautions, being made and kept wholly in non-actinic light or darkness. This material after very thorough washing was divided between a number of bottles, to each of which was added a carefully made standard solution of some chloride. Three bottles of normal potassic chloride were made in this way, one being carefully boiled, wholly filled, while hot, hermetically stoppered, and kept in perfect darkness, another being half filled and left in contact with air, but also in darkness, and the third, otherwise like the second, being exposed to bright sunlight. Bottles similarly filled with (4) decinormal potassic chloride, (5) normal zincic chloride, and (6) normal hydrochloric acid, were also prepared in yellow light, and all excepting the third were allowed to stand nearly three weeks in total darkness with occasional shaking before being filtered. Upon the expiration of this time thirty cubic centimeters of each of the filtrates were heated and treated with an excess of a solution of hydric sulphide, the zincic solution being acidified with hydrochloric acid. The precipitates were allowed to settle upon the bottoms of test tubes, where a very fair guess as to their relative quantities could be obtained. The three normal potassic chloride solutions and the hydrochloric acid appeared to yield equal amounts of mercuric sulphide, the zincic chloride very slightly less, while the decinormal solution of potassic chloride deposited no precipitate, and showed only the faintest possible coloration. These experiments showed that: —

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* The adoption of HgCl instead of Hg_2Cl_2 as the formula of mercurous chloride is purely for convenience. The true formula of this substance in the solid state seems to me doubtful.

† J. Pharm., XXVI. 108; Ann. Chim. et Phys., (3.), V. 177.

(*a*) The reaction $Hg_2Cl_2 = HgCl_2 + Hg$ is an undoubted fact.

(*b*) Light has no considerable effect on this reaction.

(*c*) Dissolved air is also not the essential factor.

(*d*) Different chlorides produce effects not very different.

(*e*) The concentration of the chlorine ions in solution is a most important factor.

(*f*) About a decigram of mercuric chloride is formed in a litre of a normal solution of potassic chloride at 20°.

The equilibrium is an interesting one; it will receive further attention in this laboratory.

That this mercuric salt actually increases the potential of the electrode containing it was easily proved by adding mercuric chloride to a decinormal calomel electrode, and comparing this electrode with a similar one in which the alkaline chloride had the same concentration. Invariably the mercuric salt raised the potential of the electrode in question. After long standing this difference gradually lessened, as the mercuric chloride was reduced; but upon shaking the difference at once appeared again. Undoubtedly in time all the excess of mercuric chloride would be reduced, until the constant amount which seems to be in equilibrium with mercurous chloride and mercury under the given conditions was reached, when the difference would disappear at constant temperature. The chief conditions of experiment being now determined, the next step was to make an accurate series of determinations of the temperature coefficient of the potential of the cells $Hg - HgCl - MCl_n - HgCl - Hg$.

Since low temperatures had been found less likely to cause the disturbing formation of mercuric salt, the two temperatures 0° and 30° were selected as the most suitable for the present purpose. Since the degree of dilution had been found to produce such an important difference in the conditions and result, solutions of three very different strengths were used. Obviously the solutions should be allowed to remain perfectly quiet at their respective temperatures for a time sufficient to allow complete establishment of the equilibrium. This time varied from several hours, in the case of the normal solution, to a few minutes, in the case of the most dilute solutions. Perhaps the best idea of the rapidity of the adjustment of equilibrium with dilute solutions may be obtained from the following series of observations, which is a fair sample. A tenth normal solution of baric chloride was placed in the apparatus with mercury and mercurous chloride, and one arm was heated to 30° in a thermostat, while the other was packed in ice.

At the very beginning of the experiment, potential = 0.0000 volt.
After five minutes, " = 0.0200 "
After ten minutes, " = 0.0218 "
After twenty minutes, " = 0.0217 "
After a hundred minutes, " = 0.0218 "

The whole apparatus was now placed in a thermostat at 30°, and a new series of observations was made.

At the beginning of the experiment, potential = 0.0218 volt.
After one minute, " = 0.0050 "
After two minutes, " = 0.0020 "
After three minutes, " = 0.0008 "
After four minutes, " = 0.0001 "
After five minutes, " = 0.0000 "
After ten minutes, " = 0.0000 "
After sixty minutes, " = 0.0000 "

Centinormal solutions behaved in the same praiseworthy fashion, but normal solutions were much more unsteady, and required a very much longer time.

As was to have been expected, decinormal and centinormal solutions gave a constant potential even when agitated, for no essential amount of mercuric salt is formed in these cases.

In order to get rid of the thermo-electric error of having the two junctions of platinum and mercury at different temperatures, an apparatus was made which allowed them to be kept at the same temperature. The mercury in each arm was connected by means of a capillary tube filled with mercury to a suitable cup in the thermostat at 30°, where the two wires from the electrometer were each connected. The tube for the electrolyte was wide in order to allow of measurement through the small conductivity of the dilute solutions. The accompanying sketch will give a better idea of the arrangement. The Peltier effect above mentioned was neglected by Gockel, because it usually amounted to less than one per cent of the whole potential to be measured; but in the present series I thought the safer course was to eliminate it.

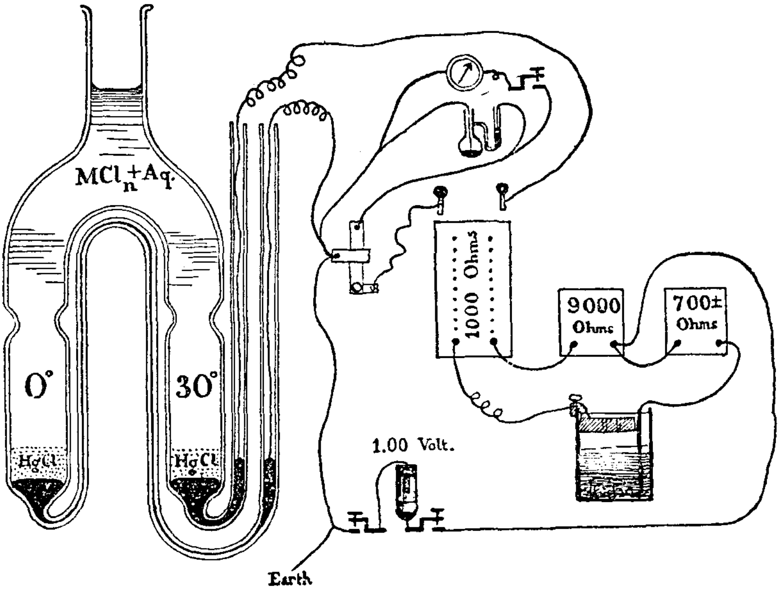

DIAGRAM OF APPARATUS.

The glass part at the left of the diagram is drawn about one third of the actual size. The remainder of the apparatus is not drawn to scale, being annexed merely to show the connections. For those familiar with the Ostwald-Poggendorff method no explanation is necessary.*

The potentials were measured as before by the Poggendorff compensation method, a sensitive galvanometer as well as a very sensitive Lippmann electrometer being used for the normal and decinormal solution, and the electrometer alone for the centinormal. In order to secure greater accuracy, the Ostwald potential box * of 1,000 ohms was connected with a Daniell "gravity" cell, and 9,700± ohms external resistance, so that

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[*] Hand- und Hilfsbuch phys. chem. Mess., pp. 252, 253.

the extremities of the box gave a difference of potential of just 0.1000 volt. This potential was verified and adjusted from day to day by means of a suitably connected Helmholtz one-volt cell, which in its turn had been compared with several standard Clark and Weston cells. The "gravity" cell remained admirably constant in potential.

The measurements involving decinormal solutions are the most accurate of those given below. The resistance of the centinormal solutions tended to diminish the accuracy with this dilution, because the galvanometer became ineffective; while the formation of mercuric chloride made uncertain the very easily measured potential of the normal solution. Many of the figures, especially those referring to normal hydric, sodic, and potassic chlorides, represent determinations made from a number of solutions of substances prepared in different ways; since these always gave the same result, only one figure is given for each.

SERIES VI.

CHLORIDES BETWEEN 0° AND 30°.

Including a larger number of Electrolytes. Cell = Hg — HgCl — MCl_n — HgCl — Hg.

MCl_n.	Temperature Coefficient. Normal Solution.	Temperature Coefficient. Decinormal Solution.	Temperature Coefficient. Centinormal Solution.
Hydrochloric acid . . .	0.00033	0.00054	0.00066 (?)
Lithic chloride	0.00063	0.00083	0.00100
Sodic chloride	0.00056	0.00078	0.00095
Potassic chloride . . .	0.00061*	0.00079	0.00094
Calcic chloride	0.00053	0.00076	. . .
Strontic chloride . . .	0.00053	0.00074	0.00092
Baric chloride	0.00053	0.00073	0.00092
Magnesic chloride . . .	. . .	0.00076	0.00096
Zincic chloride	0.00063	0.00078	0.00095
Cadmic chloride	0.00069	0.00082	0.00097
Ammonic chloride . . .	0.00058 (?)	0.00085 (?)	0.00102 (?)

* This result is somewhat lower than that obtained by Coggeshall and others, but since I repeatedly obtained it, I cannot but believe that other results must have been complicated by some modifying circumstance. See Z. Phys. Chem., XVII. 85.

Hydrochloric acid evidently occupies a position quite anomalous, and ammonic chloride also, at the other extreme, produces an electrode with a temperature coefficient considerably different from the average of the other metals. The presence of hydrogen ions in the one case, and the tendency toward the formation of amido compounds in the other might well tend to separate these two cases from the others, hence the consideration of these substances will be postponed. The remarks which immediately follow apply to the other chlorides.

It is interesting to note that each successive dilution produces about the same change in the temperature coefficient (on the average 0.00019 to 0.00018 volt). In other words, if we take the concentration of the centinormal solution as 1, of the decinormal solution as 10, and of the normal solution as 100, it is manifest that the changes in the temperature coefficient are proportional, not to the changes in the concentration itself, but to the changes in the logarithm of the concentration.

This relation immediately reminds one of the Nernst formula, in which the potential itself is a logarithmic function of the osmotic pressure of the ions; for this osmotic pressure is with dilute solutions nearly proportional to the concentration of the salt in the solution. With this idea in view, it becomes at once a matter of interest to correct the results given above for the concentrations of the respective ions; it is obvious that the normal solution of cadmic chloride must be much weaker in chlorine ions than a normal solution of potassic chloride. In order to attain this end one must first construct a logarithmic formula for the temperature coefficient involving the concentration of the surrounding electrolyte; and naturally the Nernst formula is the most convenient starting point for this construction. Considering the electrode in question in the simplest way as a source of negative ions, its potential may be assumed to have this value:—

$$\pi = \frac{R\,T}{\epsilon_0}\, l\,n\,\frac{P}{p},$$

in which π = the potential difference in question, R = the gas-constant = 1.96 × 4.24 volt-coulombs, ϵ_0 = 96,540 coulombs, $l\,n$ indicates a natural logarithm, P is the "outward tendency" (solution tension) of the chlorine in the electrode, p is the osmotic pressure of the chlorine ions in the surrounding solution, and T is the absolute temperature.

The differential of this equation is

$$d\,\pi = \frac{R}{\epsilon_0}\left[d\,T\;l\,n\frac{P}{p} + T\left(\frac{d\,P}{P} - \frac{d\,p}{p}\right)\right];$$

for we cannot assume either P or p to be constants with this form of electrode. Dividing by $d\,T$, we obtain an expression for the temperature coefficient of a single electrode, as follows: —

$$\frac{d\pi}{d\,T} = \frac{R}{\epsilon_0}\,l\,n\,\frac{P}{p} + \frac{R\,T}{\epsilon_0}\left(\frac{d\,P}{P d\,T} - \frac{d\,p}{p\,d\,T}\right).$$

Since the general tendency of the actual results is logarithmic, my observations show that the last quantity must be so small as to be without any very great influence.

In order to compute the maximum influence of this last quantity, let us assume that P is constant, hence that $dP = 0$; and the quantity considered becomes

$$-\frac{R}{\epsilon_0} \times \frac{T}{d\,T} \times \frac{d\,p}{p}.$$

But according to the law of Dalton, which applies approximately to ions,

$$T : d\,T = p : d\,p, \text{ or } \frac{T}{d\,T} \times \frac{d\,p}{p} = 1.$$

Hence in this case the last term becomes $-\frac{R}{\epsilon_0} = -0.000086$, which is only about a tenth of $\frac{d\pi}{d\,T}$ itself.

For the present, then, let us neglect this last factor, assuming that on the average $\frac{d\,P}{P} = \frac{d\,p}{p}$, and our formula becomes

$$\frac{d\pi}{d\,T} = \frac{R}{\epsilon_0}\,l\,n\,\frac{P}{p} = 0.000198 \log \frac{P}{p},$$

in which log stands for the common Briggs's logarithm.

In this case, since we are considering a negative ion, and $P > p$, it is obvious that the potential of the mercury with respect to the solution must increase with the temperature, an inference which corresponds with the facts. The current may be supposed to be carried by chlorine ions moving from the hot electrode, where they are given off, to the cold, where they combine with mercury.

We have now at our disposal a formula of the sort required; the table above furnishes values for $\frac{d\pi}{d\,T}$, and p may easily be calculated from the relation α = the dissociation factor $= \frac{\lambda_v}{\lambda_\infty}$, which changes only very slightly with the temperature. Hence we may calculate the value of P from one case, and see if the same value applies in others. If for convenience we take as our unit for p the pressure exerted by a gram equivalent of the anion when dissolved in a litre of water, it is obvious that for normal solutions $p = a$, for decinormal solutions $p = \frac{a'}{10}$, and for centinormal solutions $p = \frac{a''}{100}$. Thus with a centinormal solution of potassic chloride, where ninety-four* per cent of the salt is dissociated, we have

$$\log P = \frac{d\pi}{dT}\,\frac{1}{0.000198} + \log \frac{a''}{100}$$

$$= \frac{.00094}{.000198} + \log \frac{0.94}{100} = 4.747 - 3 + 0.973 = 2.720.$$

Hence $P = 525$. In a similar way we may find for sodium $P = 585$; evidently 550 represents a fair average value which we may adopt for this quantity upon the scale of measurement used for p. The centinormal solutions were chosen in this case because here the disturbing reaction $Hg_2Cl_2 = HgCl_2 + Hg$ is the least active. In order to get an idea of the probable error of our many hypotheses, it is well to calculate backwards and obtain a theoretical value for the temperature coefficient for other centinormal solutions besides potassic chloride from the equation

$$\frac{d\pi}{dT} = 0.000198 \log \frac{550 \times 100}{a''},$$

in which the above named values of P and p have been substituted. Performing these substitutions, and, taking for the values of the electrical conductivities the data obtained by Kohlrausch at 18°, we obtain the following table.

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* This value for a'' is of course only approximate; but the approximation is sufficiently accurate, for a large difference in a makes only a very small difference in the temperature coefficient.

COMPARISON OF THEORETICAL AND ACTUAL TEMPERATURE COEFFICIENTS.

Centinormal Solutions.

Electrolyte.	$a = \frac{\lambda_v}{\lambda_\infty}$	Temperature Coefficient of the Potential.		Difference.
		Calculated.	Found.	
Lithic chloride . .	0.92	0.00095	0.00100	+ 0.00005
Sodic chloride . .	0.93	0.00095	0.00095	+ 0.00000
Potassic chloride .	0.94	0.00095	0.00094	− 0.00001
Calcic chloride . .	Data insufficient.	0.00095 ?	0.00092 ?	. . .
Strontic chloride .	Data insufficient.	0.00095 ?	0.00092	. . .
Baric chloride . .	0.88	0.00095	0.00092	− 0.00003
Magnesic chloride .	0.885	0.00095	0.00096	+ 0.00001
Zincic chloride . .	0.885	0.00095	0.00095	± 0.00000
Cadmic chloride .	0.75	0.00097	0.00097	± 0.00000
Average				0

The examination of this table shows that the slight differences in the degree of dissociation of the various chlorides should produce no essential difference in the temperature coefficients, except in the case of cadmium, where the theoretical value corresponds exactly with that actually found. The theoretical values for cadmium, zinc, and magnesium agree sufficiently well with the experimental values, but those for barium, strontium, and calcium are too high, while that for lithium is too low. The potassium and sodium are of course the standards.

It becomes now a matter of great interest to apply this formula to the more concentrated solutions, using the value of $P = 550$, which has thus been computed from the relations of centinormal potassic and sodic chlorides. Such an application furnishes us with the best possible test of the legitimacy of our hypotheses. In the same terms as before the formula for decinormal solutions becomes

$$\frac{d\pi}{dT} = 0.000198 \, \frac{550 \times 10}{a'},$$

and that for normal solutions becomes

$$\frac{d\pi}{dT} = 0.000198\,\frac{550}{\alpha}.$$

Since calcium and strontium are essentially like barium, and magnesium is very similar to zinc, the following six metals may be taken as fair samples of the behavior of various chlorides.

COMPARISON OF THEORETICAL WITH THE ACTUAL TEMPERATURE COEFFICIENTS.

Baric Chloride.				
Strength of Solution.	$\alpha = \frac{\lambda_v}{\lambda_\infty}$	Temperature Coefficients of Potential.		Difference.
		Calculated.	Found.	
Normal	0.57	0.00059	0.00053	− .00006
Decinormal . .	0.75	0.00077	0.00073	− .00004
Centinormal . .	0.88	0.00095	0.00092	− .00003
Average				− .00004
Cadmic Chloride.				
Normal	0.20 ±	.00068	.00068	± .00000
Decinormal . .	0.47 ±	.00081	.00082	+ .00001
Centinormal . .	0.75 ±	.00097	.00097	± .00000
Average				0
Sodic Chloride.				
Normal	0.67	0.00058	.00056	− .00002
Decinormal . .	0.84	0.00076	.00078	+ .00002
Centinormal . .	0.93	0.00095	.00095	± .00000
Average				+ 0.00000

Zincic Chloride.

Strength of Solution.	$\alpha = \frac{\lambda_v}{\lambda_\infty}$	Temperature Coefficients of Potential.		Difference.
		Calculated.	Found.	
Normal	0.50	0.00060	0.00063	+ .00003
Decinormal . .	0.74	0.00077	0.00078	+ .00001
Centinormal . .	0.88	0.00095	0.00095	± .00000
Average				+ .00001
Potassic Chloride.				
Normal	0.75	0.00057	+ .00061	+ .00004
Decinormal . .	0.86	0.00075	+ .00079	+ .00004
Centinormal . .	0 94	0.00095	+ .00094	− .00001
Average				+ .00002
Lithic Chloride.				
Normal	0.62	0.00058	+ .00063	+ .00005
Decinormal . .	0.81	0.00076	+ .00083	+ .00007
Centinormal . .	0.92	0.00095	+ .00100	+ .00005
Average				+ .00006

It is evident that there is a general tendency towards the fulfilment of the conditions required by the formula. The agreement in the case of cadmium, where the effect of irregular dissociation is most apparent, is quite remarkable. The agreement in the cases of sodium and zinc is not bad; but the deviations in the case of barium on the one hand and that of potassium and lithium on the other are quite too large to be accounted for upon the basis of experimental error. It is obvious that in these cases we have some modifying circumstances; our assumption that $\frac{dP}{P} = \frac{dp}{p}$ is evidently not justified. The attempt to penetrate further into the matter by the analysis of the probable causes of P reveals that this quantity may be dependent upon several ultimate factors, — such as the changing solution pressure of the chlorine ions due to changes in temperature and the already detected formation of mercuric chloride, the changing solubility of mercurous chloride with the temperature and the presence of other chlorine ions, as well as the possibly varying "heat of formation" of mercurous chloride. Moreover, a modifying circumstance, entirely disconnected with the electrode itself, lies in the possible generation of potential from the contact of the warm solution with the cold solution. That these influences are subordinate ones, except in the cases of hydrochloric acid and ammonia, is indicated by the above tables; but further explanation must carry one too far into the region of hypothesis, and had better be postponed until a more satisfactory experimental basis is established.

The results of this paper may be summed up as follows: —

(*a*) The temperature coefficient of the potential of the calomel electrode increases with the dilution of the electrolyte.

(*b*) The kation of the electrolyte influences the result by affecting the degree of dissociation of the chloride in solution.

(*c*) Both of these effects may be approximately computed by a simple logarithmic formula based upon Nernst's hypothesis.

(*d*) The accuracy of the results is, however, affected by at least one important modifying influence, the "catalytic" decomposition of mercurous chloride into mercuric chloride and mercury.

(*e*) This side reaction is responsible for the slight inconstancy of the normal calomel electrode.

(*f*) The "decinormal electrode" is much more uniform in its behavior than the normal, and hence for some purposes might be a more useful means of measuring potential differences.

(*g*) Hydrochloric acid and ammonic chloride are anomalous in their behavior.

This research was begun in the Laboratory of Physical Chemistry at Leipsic, upon the suggestion of Professor Ostwald. It was continued by his kind consent at the Chemical Laboratory of Harvard College, and I hope that some of the problems left unsettled may be solved by future work here. Especially is it my intention to apply the differential equations to other cases, such as an electrode of zinc in a zincic salt.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

NOTE ON THE RATE OF DEHYDRATION OF CRYSTALLIZED SALTS.

By Theodore William Richards.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

NOTE ON THE RATE OF DEHYDRATION OF CRYSTALLIZED SALTS.

By Theodore William Richards.

Presented May 12, 1897.

In the course of the investigation of the atomic weights of barium and strontium, a few observations were made upon the rate of dehydration of several of the salts of these metals. These observations supplement the work of Lescœur,* Roozeboom,† and others, concerning the vapor tension of water contained in crystallized salts. It was found that the rate of the withdrawal of water by means of a constant desiccating agent varied very greatly with different substances, as well as with different hydrates of the same substance. Baric chloride, for example, exposed to a dry atmosphere at first effloresces with great rapidity, and then, after it has lost one of its molecules of water of crystallization, continues to be dehydrated at a much slower rate. This is nothing more than was to be expected, for the rate of dehydration must be approximately proportional to the tension of the aqueous vapor in the salt, provided that the aqueous vapor is equably removed from the surrounding atmosphere. It is obvious, therefore, that successive weighings of any material which is gradually efflorescing may furnish a useful clue to the relative vapor tensions of the successive molecules of crystal water contained in that substance.

As an example of the definiteness of the change of rate, one of several concordant experiments upon baric cloride may be cited. 1.2223 grams of the finely powdered crystallized salt were weighed out in a small crucible; and with this substance was mixed a small amount of pure washed and ignited asbestos, in order to allow freer circulation of air. This precaution was not necessary for the success of the experiment, although it had been found to increase somewhat the sharpness in the change in the rate of dehydration. The crucible was now placed in a small desiccator containing phosphoric oxide, and the whole was placed in a thermostat maintained at 30°. From time to time the crucible was rapidly weighed, the phosphoric anhydride being stirred in order to expose a new surface to the moist air. The results of this experiment are recorded below.

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* Ann. Chim. Phys., (6.), XIX. 533, XXI. 511, (7.), II. 78.

† Comptes Rendus, CX. 134; Zeit. Phys. Ch., II. 449; also IV. 31, etc. etc.

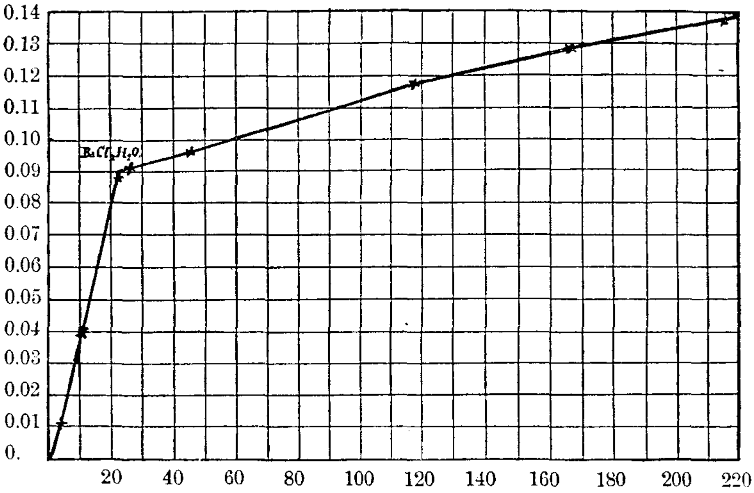
Rate of Dehydration of Baric Chloride.

Time (from beginning) in Hours.	Time (from previous weighing) in Hours.	Total Loss (in Grams).	Loss between two weighings (in Grams).	Rate of Loss — Milligrams per Hour.
0	0	0	0	
0.5	0.5	.0010	.0010	2.0
4.3	3.8	.0109	.0099	2.6
11.0	6.7	.0400	.0291	4.3
22.8	11.8	.0886	.0486	4.1
26.7	3.9	.0914	.0028	0.72
45.8	19.1	.0964	.0050	0.26
118	72.2	.1174	.0210	0.29
166	48.0	.1284	.0110	0.23
214	48.0	.1374	.0090	0.19

After several days more, the salt had lost very nearly all of its crystal water, although the last portions, which must have been in the centre of the various masses constituting the powder, naturally left more and more slowly. Exposed to the somewhat moist air of the laboratory, the salt regained in a few days all the water which it had lost.

The only remarkable thing about this rather commonplace experiment was the suddenness of the change in the rate after the first molecule of water of crystallization (0.0900 grams) had gone. Graphic representation will make the point clearer. In the accompanying diagram, the loss of water (in grams) is plotted vertically, while time (in hours) is plotted horizontally.

Rate of Dehydration of Baric Cloride.



The sharp angle occurs exactly at the point corresponding to $BaCl_2H_2O$. A number of other salts also were experimented upon, — those with little water of crystallization usually behaving in the same general manner as baric chloride, while those with much water of crystallization (such as sodic carbonate) gave less angular curves, in which the various hydrates were only slightly, if at all, perceptible. It is well known that all the hydrates are not necessarily formed during such a dehydration. In order to obtain a sharp change with any salt, it is manifest that one must use a desiccating agent which does not remove the water much faster from the surface than it can be supplied by diffusion from below. Hence from such a substance as sodic carbonate one obtains more satisfactory results by using diluted sulphuric acid instead of phosphoric oxide in the desiccator; by no means a new idea. For any given case, the aqueous vapor tension of the desiccating agent should be not much less than that of the salt during the removal of the water corresponding to the second limb of the desired curve.

It is convenient to have at hand for this purpose a table giving the approximate strength of sulphuric acid necessary to obtain a given tension of aqueous vapor at a given temperature. The data for such a table may be found in the work of Regnault,* and Lunge and Isler.†

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* Ann. Chim. Phys., (3.), XV. 179. Landolt und Börnstein, Tabellen, 1894, p. 65.

† Z. Angew. Chem., 1890, p. 129. Landolt und Börnstein, p. 196.

Below is given a partial table of this sort, which suffices for ordinary work with crystallized salts. It was obtained from the data above mentioned by graphic interpolation. The specific gravities of diluted sulphuric acid given in the last three columns are taken at 15°, and referred to water at 4°; — sulphuric acid of any strength given below placed in a desiccator kept at the temperature given at the top of the column, is then capable of yielding aqueous vapor at a tension found in the first column. Since the curves corresponding to Regnault's data are not quite regular, these values are only near approximations.

SPECIFIC GRAVITIES OF SULPHURIC ACID CAPABLE OF YIELDING AQUEOUS VAPOR AT VARIOUS TENSIONS.

Tension of Aqueous Vapor.	20° C.	25° C.	30° C.
0	1.838	1.838	1.838
0.25	1.750	1.763	1.772
0.50	1.693	1.710	1.726
1.00	1.642	1.666	1.688
1.50	1.603	1.629	1.652
2.00	1.570	1.600	1.629
2.50	1.538	1.575	1.605
3.00	1.510	1.550	1.589
4.00	1.470	1.513	1.555
5.00	1.434	1.482	1.530
6.00	1.404	1.455	1.504
7.00	1.378	1.429	1.482
8.00	1.355	1.405	1.455
10.00	1.308	1.368	1.430
15.00	1.16	1.28	1.353

This table is also of practical use in preparing dry crystallized substances. For instance, crystallized oxalic acid, so much used in making standard solutions, is best prepared by placing the powder over sulphuric acid of specific gravities 1.20 to 1.50; for the crystallized substance does not lose an essential amount of water at 22° in an atmosphere containing aqueous vapor at a tension of 4 millimeters; while the aqueous vapor tension of its saturated solution is more than 15 millimeters.*

It is almost needless to call attention to the fact, recognized as a matter of course by any one who has especially studied the subject of water of crystallization, that the temperatures of dehydration given in text-books are often wholly indeterminate and almost meaningless, since the tensions of the aqueous vapor in the surrounding atmosphere are frequently not given. Much of our literature upon this subject needs a systematic revision.

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* W. D. Bancroft has recently published statements bearing upon this subject, some of which are founded upon slight experimental evidence, under the title "Solids and Vapors." (The Physical Review, Ithaca, N. Y., Vol. III. p. 401, and The Journal of Physical Chemistry, Ithaca, N. Y., Vol. I. p. 345.)

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SUGGESTIONS FOR THE DEVELOPMENT OF THE ARTS AND SCIENCES.

By W. R. Livermore, Major of Engineers, U. S. Army.

SUGGESTIONS FOR THE DEVELOPMENT OF THE ARTS AND SCIENCES.

By W. R. Livermore, Major of Engineers, U. S. Army.

Presented June 9, 1897.

It is often said that we are rapidly approaching a limit to the development of the Arts and Sciences; that the next century will not witness as much progress in this direction as the present. We have discovered the correlation of forces, and the conservation of energy, found the mechanical equivalent of heat, formulated an electro-magnetic theory of light, and made wonderful applications of steam and electricity. We have found the missing link in the chain of evolution. There are strong reasons, however, to believe that the Arts and Sciences will make far greater progress in the immediate future than ever in the past.

The words Arts and Sciences are used in the most general sense. Both relate to investigations of truth, but Science inquires for the sake of knowledge, Art for the sake of production. A Science teaches us to know, an Art to do. In Art truth is a means to an end, in Science it is the only end.

No Arts are possible unless they are founded on Sciences, and Sciences depend on generalizations. By induction individuals are raised to generals, and these to higher generalities. By deduction universals are brought down to lower genera and to individuals. A knowledge of facts is mainly useful as a basis for Science. Whatever may be the aim of Philosophy or Religion, the final object of the Arts and Sciences should be to ascertain laws to apply to acts.

The tendency of the age has been to specialize. As a reaction against the mediæval practice of framing theories on insufficient foundations, most of the scientific work of modern times has been devoted to collecting facts, arranging and classifying them; and those who have devoted their lives to investigating abstract laws and principles have been out of touch with those who have handled the facts to which the laws apply. All the professions have been driven into independent channels. A university town has been likened by its inhabitants to an archipelago.

It has been said that the chemist and the physicist should be diametrically opposite in their ways of thinking and working. If so it is very important that the results of each should be put in proper shape to be utilized by the other. The chemist requires aid from the physicist, the physicist from the mathematician, the engineer from all. The historian requires aid from the linguist, and the economist from the historian. Every art and science, and every calling in life, is dependent for its proper development on every other, and should be able to apply the results that have been worked out by specialists in all branches.

Systematic co-operation is still more requisite between those of the same profession than between those of different professions; it is in fact another name for civilization. Without co-operation we should soon be reduced to the condition of paleolithic man, and forced to hunt reindeer with clubs, or if we should congregate it would only be to sit on shell mounds and eat oysters.

It is time to build up Science on broad foundations. We cannot all be specialists hereafter. The results of our labor must be put together in such shape as to be utilized. And to this end new means of communication must be employed.

In every branch of science a complicated system of technical terms and hieroglyphics has been employed as a screen to keep off intruders and to hide the precious jewels from the profane glance of those who have not dug them.

Many of the papers read before our own society are intelligible only to the speakers. The listeners only recognize the language by occasional articles or prepositions.

In our efforts to scale the heavens and find out its secrets, we have been paralyzed by a confusion of tongues like our ancestors in the valley of the Euphrates four thousand years ago.

Technical terms and symbols are necessary and proper tools for the specialist to work with, but they are not the fruits of his labor to turn over to the world.

The technical language that acts as a barrier between different sciences is far from being all-sufficient for its own science. The specialist is forced to spend a valuable part of his life in assimilating the work of others before he can hope to advance the bounds of science even in the narrow field in which he is working. This involves a great dissipation of energy. Moreover, many sciences are so buried in their own symbols that the specialists are mystified about the purport of their discoveries. They take abstract formulæ to be the end, and not the means, of their work.

Hence the fear is not ungrounded that, under the present system, we cannot look for as much progress in the future as in the past.

In the reaction against wild speculation we should not go so far as to lose sight of the object of our work. Our predecessors built towers on such narrow foundations that they blew over. We have seen their trouble and have dug the foundations for a more stable edifice; and since the confusion of tongues, we have still been working along, cutting stone, dressing and polishing it, laying a few courses, and putting up scaffolding. But most of the stone is still in the quarries; it has yet to be handled; the building is to be erected; but the roads are bad; railroads and derricks are required, for we have now only hammers and chisels, and the quarries are so congested with stone that it must soon be removed.

To make co-operation effective, means must be devised by which the raw material may be handled, not only by the specialists, who have accumulated it, but also by all others working in allied sciences.

I do not refer to attempts to popularize science by presenting the shadow rather than the substance. All results, everything that is known, must be presented in such form as to be intelligible with the least expenditure of mental effort.

Neither do I refer to the instruction of youth, although I think that some of the methods required to build up science could also be applied to education.

The science and art of co-operative thought have yet to be created. System and tools must be invented both for the science and for the art. The nineteenth century has produced machinery for manufacture. The twentieth century will produce machinery for thinking. We can now only surmise what these methods and tools will be, but it is time to consider, and it is the duty of all interested in the Arts and Sciences to suggest.

The methods now employed for handling facts and principles are: —

First, making the human brain a kind of receptacle and pumping into it a little information during a short period of tutelage.

Secondly, consulting Encyclopædias and Libraries.

Thirdly, consulting professional experts.

These methods are insufficient. If the engineer has to make some new application of the principles of physics, is it convenient for him to read through volume after volume written in foreign and occult languages, tempered with mathematical hieroglyphics that conceal rather than express the author's meaning? Or must he renew the experiments that have been made all over the world, invent his own apparatus, and draw his own inferences? Or shall he go to some learned physicist and ask him to explain all he knows about his science? Occasionally this would be very pleasant for both parties, — if the engineer did not want to know too much or too often, or if he paid enough for the advice.

These methods all have their advantages, but they will require modification or perfection hereafter. A great deal that is now hidden in symbols can be expressed in plain intelligible language, but language can no longer be the only means of communicating thought. Graphic methods are already employed on a small scale to represent mechanical and physical principles; so are synoptical tables, charts, etc. But these methods and their applications should be much extended, and in connection with them the very hieroglyphics employed by the specialists can be turned to good account.

We must use our eyes as well as our ears. Speech is addressed to the ear which receives but one impression at a time. We must avail ourselves of two dimensions of space instead of one. Suppose the problem were to find a needle in a dark room. We could find it much quicker by lighting a lamp than by feeling about in the dark until we had brought our fingers in contact with every part of the surface. We do indeed use our eyes in reading, but we read only words, words, words, that are addressed to the ear through the eye and convey only a single train of thought. We use our eyes like a blind man, and we follow King Lear's advice to Gloucester: "Look with thine ears . . . and, like a scurvy politician, seem to see the things thou dost not."

There is always more or less opposition to new methods. It is claimed by some that the labor spent in acquiring knowledge is necessary to improve the mind. One of the advocates of this doctrine commanded a flat-boat on the Mississippi River and combined this function with that of a preacher of the Gospel. He declined to tell his congregation where the text was to be found, because, he said, if they would search the Scriptures as he had searched them, they would find there not only his text, "but many other texts as would do 'em much good to read 'em."

Everything must be put in synoptic or cartographic form if possible. If we do not make such charts on paper, we must make them in our brain. By the present system the mind is overtaxed with the effort. If the charts are first made on paper, they are quickly photographed on the mind, and then the old methods can be applied in connection with them. If you have a map of the country, the guide-book will help to make it more intelligible and interesting. Meander through the country by all means, but look at it from a balloon with a field glass on every available opportunity. Keep your map with you, and years hence you will recall what you have seen.

Scientific books should be supplied with classified tables of contents, so complete as to recall every idea worth remembering. The books might be so written as to be intelligible when opened in the middle. Where algebraic or other signs are used, they should also be thoroughly indexed. Models, of course, are far better than pictures. It is better to make use of three dimensions whenever possible rather than two, and movable models would give us four dimensions to work with. Neither charts nor models fatigue the mind any more than sentences, but in the same time they teach more and make more lasting impressions.

The systematic reduction of knowledge opens the way to systematic co-operation. The centrifugal tendencies of the age have been useful in scattering explorers over a wide field, but the waste of labor has been incalculable,— one after another has trodden the same path, when each should have begun his work where the other had ended. If facts and laws and principles are properly tabulated as soon as they are discovered, it will not be necessary for each man to set up an independent hypothesis, but the work of investigation can be properly distributed.

The methods employed in military operations for deploying scouts to explore the field of operations could be used to good advantage in all the sciences.

Napoleon and his staff were on the banks of the Red Sea at low water at the spot where the children of Israel were said to have crossed. After sunset they lost their path, and as they were wandering among the sands the rapidly returning tide surrounded them, and they would have met with the fate of Pharaoh, but Napoleon collected his escort around him in several concentric circles, each horseman facing outward. He then ordered them to advance, each in the direction he was facing. When the horse of the leader of one of these files lost his foothold and began to swim, the file drew back and followed in the direction of another file which had not yet lost its firm ground. The files thrown out in every direction were in this way successively withdrawn, till all were following in the direction of the one which had a stable footing. Thus the escape was effected, and by a similar method of co-operation the process of induction could be facilitated in all sciences.

In applying these principles to the separate sciences, Mathematics, Physics, and Engineering may be considered together.

Mathematics is usually spoken of as a deductive science, but it is also inductive. Klein divides the mathematicians into three classes, the logicians, formulists, and intuitionists. The intuitionists lay particular stress on geometrical intuition, — not in pure geometry only, but in all branches of mathematics. "What Benjamin Peirce calls geometrizing a mathematical question," says Klein, "seems to express the same idea." Each class is useful in its own sphere, but hereafter the sphere of the intuitionist will be vastly extended.

In mathematics and physics all analytical work can be put into geometrical shape, and so expressed that one or two pages will not only indicate but explain the work of a volume and help to recall its contents. In Analytic Geometry, as ordinarily treated, the Geometry is the object, the Algebra the means. In cartographic representation the Geometry not only explains itself, but explains the Algebra also.

Algebraical Formulæ should also be tabulated by themselves for some purposes. Tables of Integrals should be made as complete and systematic as possible, and form the basis for a treatment of the Integral Calculus.

The higher branches of mathematics lend themselves as readily to cartographic representation as the simpler branches.

The purely analytical methods of much of the mathematics of the nineteenth century make it comprehensible only to a mathematician. and only to him when he begins at the first chapter.

I had occasion once to look into a question of mathematical physics that was not so elementary as to be found in an engineer's pocket-book; and so I consulted a treatise on the special branch in which I was working. From the index and table of contents, I had no trouble in finding the place, but did not know what the letters stood for. I read the chapter through without learning, and then read the chapter before it. There were the same signs, and I was referred back to chapter after chapter, then to another book on general physics, which I read half through, and then to a book on mathematics, with no better result. Then I took up one of the books on physics again, and began at the Preface. I found nothing about the signs, but much about the Cambridge Tripos. I had not been connected with any university for several years, and I thought a Tripos was a thing to set a theodolite on. I looked in the dictionary, and found that it was a writer of Latin verses on the back of a slip of paper containing the names of bachelors who were highest in the list. That explained everything. The Latin verses were the end and motive of the whole system. The books were not meant to be understood by anybody who did not go through the whole mill. In the innocence of my heart I wanted to find out something about fog-signals to save the lives of seamen, and I had been referred to the little Latin verses for boys. I then worked out the problem of general principles in less than a tenth of the time I had spent in looking it up.

Mathematics is regarded as an occult science, whereas in reality, if you only know what the letters mean, it is the plainest common sense. One of the leading scientists of America told me that he did not think the higher branches of mathematics were of any practical use; and one of the most noted inventors of the day even said, "Mathematics ain't no good." Before mathematicians can take the stand in the world to which their work entitles them, they must express their results in better shape.

In the science of Physics much would be gained by more perfect co-operation. The time has not yet arrived when all the laboratories in the world or in the country can so combine their labor that no work shall be uselessly duplicated, but doubtless there is more co-operation in a quiet way than is generally known.

In Physics and Engineering, graphic methods have long been employed. In 1892 the committee appointed by the British Association to look into this subject made its second report. This Association, and others of its type, have inaugurated a system of co-operation in science, but nothing to compare with what will soon be required. The report says: "It does not require much acquaintance with the subject to realize that there is scarcely a treatise or publication dealing with mechanical science that does not employ some kind of graphical expression as a means of exposition or calculation." These reports give a good index to the work up to that date.

Graphic methods afford the best means of mapping laws, and complete maps of all that are known would not only help to recall them, but would also aid in the solution of problems.

The immediate future will probably see a greater advance in the science of Physics than all past ages together. The correlation of forces and conservation of energy have already been established, but we know little as yet of the nature of the correlation except between light and electricity. We have not yet determined the nature of the ether, or that of atoms. Ethers have been hypothecated that answer for special purposes. The problem is to get one to do all the work required, and until that is found physicists and chemists should formulate and tabulate as simply as possible the conditions it must fulfil to account for phenomena. The solution of the problem will not be far away.

Trautwine's Pocket-Book for Engineers was first written as a protest against mathematics. It was a great help for a certain class of engineers, for it gave them the results of the work of mathematicians which they could not comprehend. It was also a help to engineers who were mathematicians, but who had forgotten some of the formulæ. What is now needed is a handbook which shall also express the mathematics in as clear a form as the results were expressed in Trautwine's book, and some progress has already been made in that direction.

The principles of Chemistry are as capable of cartographic representation as those of any other science. Mr. Sleeper of Jersey City appears to be doing good work in this direction.

In 1854, Dr. J. P. Cooke, our late President, prepared a table showing the relation of the properties of the elements to their atomic weights, in connection with a paper published by our society. Dr. Cooke then said: "To my mind chemistry will then become a perfect science when all substances have been classed in a series of homologues, and when we can make a table which shall contain not only every known substance, but also every possible one. and when by means of a few general formulæ we shall be able to express all the properties of matter, so that, when the series of the substance and its place in the series are given, we shall be able to calculate, — nay, predict its properties with absolute certainty."

Dr. Cooke's formula $(a + n d)$ expressed the same idea, — viz. the regular increase in the scale of atomic weights in each series, — whereas the law of the octaves of Newlands and Mendelcyeff only admits of seven elements in each period, and is inconsistent with this regular increase, which, as every new discovery tends to show, lies at the foundation of atomic chemistry.

All sciences owe a debt of gratitude to the naturalists for developing methods of classification that have been applied with such success. The advantages of public museums are too well recognized to require comment.

Of all sciences Geography was perhaps the first to be thoroughly expressed by the cartographic method. A picture suggests a map, and a map representing the prominent natural features suggests a map showing the political divisions of the land, the distribution of animal and vegetable life, etc. Geological Maps show the distribution of rocks, and Historical Maps the distribution of political supremacy at different ages.

I have already had the pleasure of calling the attention of the Academy to my own work in preparing a series of maps, designed to show the political divisions of Europe in every decade, or even at shorter intervals, if necessary to make the representation continuous and complete in respect to time, and to present a complete panorama of history. In turning over the pages we see the growth and decline of nations and tribes. They move along as in a zoetrope or kinetoscope. In this Atlas, History is expressed in three dimensions. To find the state of Europe at a definite time, we only have to turn to the map of the date next following. To find the time that any nation or race first predominated in any spot, we only have to turn the leaves back until the color of that spot changes. The figures near the boundary line, when known, indicate the precise year in which the change occurred. No other atlas and no encyclopædia has ever attempted to supply complete information of such a character. Specialists have worked on such problems, each in his own sphere, but the results of their work lie buried in hundreds of periodicals and monographs, and have never before been combined and plotted. The objection has been raised that the use of charts takes away all the romance of history which is attached to the personal narrative, but it is by no means claimed that a knowledge of the geographical distribution of political supremacy comprises all that is useful in History. It is, however, the alphabet and foundation of Historical Science. Without it History is incomprehensible. If the reader keeps this Atlas before him and turns over its pages as he reads, the text will be clearer, the ideas will become associated with those already acquired, and the whole subject systematized and photographed on the mind. The Atlas serves as a nucleus for the crystallization of all associated ideas.

Statistical Science can only be properly handled in cartographic form.

The Historical Drama represents, in the four dimensions of space and time, the narrative and all the phases of history; the scenery and costumes, the manners and customs, the ideas and emotions, are presented simultaneously to the eye and the ear, so naturally as to produce a vivid and lasting impression. If artists and historians would combine their efforts to perfect the Drama, it could be made a powerful auxiliary to Historical Science.

The science and art of war require as much study and practice as any other science and art. But a soldier may not always be killing. He acquires practice in the elements of his profession in camp and garrison, but he can only apply them to a battle or a campaign by representing it in the field or upon a map. To aid in making this representation of war conform to the reality, all the information about the factors that influence a battle have been expressed in cartographic form by tabulating signs and abbreviations that would be meaningless in themselves, but which serve to recall the contents of a volume. These tables are so arranged as to show the numerical value of the influences that affect a battle or a campaign, and, in connection with the scales and other apparatus, enable the umpire to make the representation of warfare as perfect as possible. Most of the methods that have been found so convenient in this exercise are equally applicable to any other art.

I think that some of the cartographic methods can be applied with great advantage to the study of languages, especially for a scientific man, who is obliged to read foreign languages from time to time without keeping in constant practice. A method that has been employed in reading French, Spanish, Italian, Latin, Greek, German, and Russian is as follows. One chart shows all the prefixes, affixes, etc. Another shows one thousand or more of the most common roots, arranged alphabetically. Ninety-nine words out of a hundred, more or less, can be found with these charts, and the labor of consulting the lexicon reduced in proportion. But that is not all. After you have used the chart a while, you recall what you are looking for as soon as you turn your head toward the chart, and often do not really look at it. Finally, it becomes photographed in your mind. After several years, if you take up the chart again, the associated impressions will come back to you. Special charts are made for special subjects, to be used in connection with the general chart.

In tabulating a language to speak it, a different method is employed. The chart of inflections is the same, but the words are arranged, not alphabetically, but according to meaning. When the object of language is merely to make your thoughts understood in a general way, without reference to elegance of expression, only a small vocabulary is required. If the words are arranged in the charts according to their meaning, the foreign words become associated in the mind with the ideas they express, and it is not necessary to think first in your native language and then translate alphabetically.

After applying these principles to one language of the Aryan family, it is very easy to apply it to another, and it is about as easy to learn to read ten languages by this method as one by the ordinary one.

For the commercial traveller this method may not be as expeditious as the more natural one, to accompany the word with the action, the action with the word, if the object be only to go to the door, turn the knob, look out of the window, etc.; but the scientific man has other needs.

The Fine Arts are more or less dependent for their production upon the useful arts and the sciences. The same methods can be employed to investigate and communicate the principles on which they are founded.

Sculpture and Painting are addressed to the eye.

Sculpture is expressed in three dimensions of space. In contemplating a beautiful figure, we see and feel what we cannot express in sentences.

Painting is expressed in two dimensions, and through the medium of form and color impresses upon the mind volumes of thought and feeling.

Music is addressed to the ear; it depends upon a succession of sounds, and the music of the savage is only a melody that may be expressed on a scale by a single line or a succession of dots. On the other hand, the music of an orchestra is composed of hundreds of sounds of various qualities, which in the opera combine with the dramatic elements to excite the thoughts and emotions. The music of the ancients bears the same relation to the music of the future that the Arts and Sciences of the past bear to the Arts and Sciences of the future.

Poetry, too, is addressed to the ear. A simple ballad suggests a simple train of thought, or perhaps a gentle shade of feeling; but the poetry of Shakespeare suggests with each word a dozen images. In the early youth of nations, before the Arts and Sciences were fully developed, the energies of the intellect were mainly directed upon the language. The old Celtic bards were never allowed to speak except in blank verse. In the poetry of Homer and Shakespeare we find a vigor and an inspiration utterly wanting in later poetry. Abbott, in his Shakespearian Grammar, says: "We may perhaps claim some superiority in completeness and perspicuity for modern English, but if we were to appeal on this ground to the shade of Shakespeare in the words of Antonio in the Tempest, 'Do you not hear me speak?' we might fairly be crushed with the reply of Sebastian, 'I do, and surely it is a sleepy language.'"

Language may be regarded as the mother of all the sciences. She has brought them forth and nursed them, and they still depend upon her to introduce them to society. But it is time for them to cast off their swaddling clothes and learn to walk alone. In the future, language will not be overtaxed as it is at present, but will be none the less useful in its proper sphere. Thought must have other means of expression before all can co-operate to build up sciences to best advantage.

The earliest science was purely deductive. Philosophers evolved knowledge from the inner consciousness. The science of modern times has been mainly inductive, but the time has come when the results of induction must be put in shape to be combined in broader generalizations, which will enable the principles to be applied by deduction to cases that have not yet come within the scope of experience.

To Induction and Deduction we must now add Reduction in order to realize the full benefit of co-operation.

Societies like ours can exercise some influence in a quiet way to encourage co-operation. Our meetings also have more immediate advantages. The chief object in reading papers here is not to instruct the audience, but to lay before the society the lines of the author's work. Some suggestions may be brought out in the general discussion, but far more useful ones in personal conversation. Hence it is only at the social meetings that the full benefit can be expected.

The necessity for co-operation has long been recognized in the useful arts. In our factories we see men working together for a common purpose, in such a way that each may add the results of his labor to those of the others; in an army co-operation is carried to the highest development. It is to be hoped that the future will witness large armies of scientists engaged not merely in collecting information and classifying it, but also in making systematic inductions and applying them to Arts and Sciences in general, and working in such a manner that each may add his results to the general stock.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE 3, 4, 5 TRIBROMANILINE AND SOME DERIVATIVES OF UNSYMMETRICAL TRIBROMBENZOL.

By C. Loring Jackson and F. B. Gallivan.

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By C. Loring Jackson and F. B. Gallivan.

Presented May 12, 1897.

In the course of an attempt to prepare the vicinal tetrabrombenzol, which unfortunately did not lead to the desired result, we had occasion to make the 3, 4, 5 tribromaniline, when to our surprise our product melted at 118° to 119°, whereas Koerner, who discovered the substance, says of it, "non fondente a 130°, e che, a quanto pare, si scompone per un più forte riscaldamento." * As the statement quoted from Koerner contained all that was known of the properties of the substance, except that he says also that it forms salts, we have made a more careful study of this tribromaniline in order to characterize it. Our melting point not only differed from Koerner's, but also was essentially identical with that of the ordinary tribromaniline $NH_2 1, Br_3$ 2, 4, 6. — which melts at 118° according to Koerner, at 119°–120° according to Fittig and Buchner. It was necessary, therefore, in the first place to prove that our substance was the tribromaniline $NH_2 1, Br_3$ 3, 4, 5, even although from our knowledge of the positions usually taken by bromine atoms on the benzol ring it seemed hardly possible that a body formed by the action of bromine on paranitraniline could have a different constitution. To make the proof absolute we eliminated the amido group from our tribromaniline, when we found that the vicinal tribrombenzol melting at 87° and crystallizing in tables was formed with remarkable ease. It follows, therefore, that Koerner's statement that the tribromaniline ($NH_2 1$, Br 3, Br 4, Br 5) does not melt even at 130° is incorrect, and that it melts at 118°–119°. We have added to the description of the compounds of this tribromaniline which follows an account of some other substances obtained in our

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* Gazz. Chim., 1874, p. 409.

attempts to make vicinal tetrabrombenzol, and also a few corrections and additions to our paper on "On Some Derivatives of Unsymmetrical Tribrombenzol" [*] published somewhat more than a year ago.

3, 4, 5 TRIBROMANILINE, $C_6H_2Br_3NH_2$.

To prepare this substance [†] paranitraniline was suspended in water, and converted by the addition of bromine into dibromparanitraniline. Then fifty grams of this product were mixed in a flask with hydrobromic acid (boiling at 125°), and sodic nitrite added in excess. After the last portion of the nitrite had been decomposed, a large excess of hydrobromic acid was added, and the contents of the flask allowed to stand over night. The diazo compound formed was then decomposed by heating on the steam bath; and the tribromnitrobenzol obtained was reduced with tin and hydrochloric acid without any previous purification, when most of the tribromaniline separated in the solid state, although a small amount could be recovered from the hydrochloric acid solution. It was purified by crystallization from alcohol or hot ligroin.

Properties. — It crystallizes from alcohol and water in slender white needles, rather short and pointed at both ends. Although it crystallizes in needles like the ordinary tribromaniline, it differs from that in habit, as we could not succeed in obtaining very long needles similar to those which are so characteristic of the $NH_2$1, Br 2, Br 4, Br 6 isomere. It melts between 118° and 119°, while the highest melting point given for the isomeric form is that of Fittig and Buchner, 119°–120°. It is soluble in ether, chloroform, benzol, acetone, or alcohol; slightly soluble in cold, soluble in hot ligroin; essentially insoluble in water. Dilute alcohol or hot ligroin is the best solvent for it. It forms salts more readily than the NH_2 1, Br_3 2, 4, 6 tribromaniline, and a little less readily than the NH_2 1, Br_3 2, 4, 5 tribromaniline.[‡] With bromine it gives pentabromaniline. By the elimination of its amido group it is converted into the vicinal tribrombenzol melting at 87°.

CHLORIDE OF TRIBROMANILINE, $NH_2$1, Br_3 3, 4, 5.

This salt could be made by boiling the tribromaniline with a large excess of concentrated hydrochloric acid, but was prepared for analysis by the more convenient method of dissolving the tribromaniline in benzol and adding a strong solution of hydrochloric acid * when the salt was precipitated.

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[*] Amer. Chem. Journ., XVIII. 238.

[†] Koerner, Gazz. Chim., 1874, pp. 347, 390.

[‡] Amer. Chem. Journ., XVIII. 247.

0.4976 gram of the salt gave, after the base had been removed by ammonic hydrate, 0.1911 gram of argentic chloride.

	Calculated for $C_6H_2Br_3NH_3Cl$.	Found.
Chlorine	9.69	9.50

Properties. — The salt crystallizes unaltered in white needles from hot water to which a few drops of hydrochloric acid have been added; but if it is boiled with water alone, it undergoes a partial decomposition. This salt is, therefore, much more stable than the chloride of the $NH_2 1$, Br_3 2, 4, 6 tribromaniline, which is decomposed completely by water. It is slightly soluble in benzol; insoluble in ligroin or ether.

BROMIDE OF TRIBROMANILINE, $NH_2 1$, Br_3 3, 4, 5.

This salt was made by adding a strong aqueous solution of hydrobromic acid to two grams of the tribromaniline dissolved in benzol. The white precipitate formed was filtered out, washed with benzol, dried, and analyzed with the following result: —

0.3841 gram of the salt gave, after the base had been precipitated with ammonic hydrate, 0.1771 gram of argentic bromide.

	Calculated for $C_6H_2Br_3NH_3Br$.	Found.
Bromine	19.47	19.63

The bromide resembles the chloride in its properties, and, although slightly more unstable, is still much more stable than the bromide of the tribromaniline $NH_2 1$, Br_3 2, 4, 6.

SULPHATE OF TRIBROMANILINE $NH_2 1$, Br_3 3, 4, 5.

To prepare this salt three grams of the tribromaniline were heated with moderately strong sulphuric acid. The tribromaniline soon dissolved, and on cooling the solution deposited fine large plates of the sulphate, which were purified by recrystallization from water slightly acidified with sulphuric acid, dried, and analyzed with the following result: —

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* In order to obtain the chloride of the NH_2 1, Br_3 2, 4, 6 tribromaniline, gaseous hydrochloric acid must be used.

0.4671 gram of the substance, after treatment with ammonic hydrate, gave 0.1417 gram of baric sulphate.

	Calculated for $(C_6H_2Br_3NH_2)_2H_2SO_4$.	Found.
SO_4	12.66	12.49

Properties. — The salt crystallizes from dilute sulphuric acid in broad white shining plates, which are soluble in water; but if its aqueous solution is heated, it decomposes partially into the tribromaniline and sulphuric acid. In the presence of a little sulphuric acid, on the other hand, the aqueous solution can be heated without decomposition. The salt is soluble in alcohol, and its solubility is increased by heat; insoluble in benzol, chloroform, or ether.

TRIBROMPHENYLURETHANE, $C_6H_2Br_3NHCOOC_2H_5$, NH 1, Br_3 3, 4, 5.

This substance was prepared by boiling a benzol solution of ten grams of the tribromaniline with eight grams of chlorocarbonic ethyl ester in a flask with a return condenser. After heating for five hours, as no more hydrochloric acid was given off, the mixture was allowed to cool, when crystals appeared, which were filtered out, and crystallized from dilute alcohol until they showed the constant melting point 169°–170°. The substance was then dried at 100°, and analyzed with the following results: —

I. 0.1915 gram of the substance gave 0.2708 gram of argentic bromide by the method of Carius.

II. 0.1771 gram of the substance gave 0.2473 gram of argentic bromide by the method of Carius.

	Calculated for $C_6H_2Br_3NHCOOC_2H_5$.	Found.	
		I.	II.
Bromine	59.70	60.20	59.43

The $NH_2$1, Br_3 2, 4, 6 tribromaniline gives no urethane under these conditions.

Properties. — This tribromphenylurethane crystallizes from a mixture of alcohol and water in thin white rhombic plates frequently with the acute angles bevelled by two other planes making a very obtuse angle with the sides of the original rhomb. It melts at 169°–170°; and is easily soluble in alcohol, ether, benzol, or chloroform; essentially insoluble in cold ligroin, soluble in hot. Strong hydrochloric acid in the cold has no apparent action on it. Strong nitric acid or strong sulphuric acid dissolves it, and the addition of water to the solution gives a white precipitate.

When the tribromphenylurethane was boiled with aniline under a reverse condenser, a substance was obtained, after removing the excess of aniline with dilute hydrochloric acid, which crystallized from alcohol in very long needles, melted at 235°, and contained no halogen. There was no doubt, therefore, that it was diphenylurea $(C_6H_5NH)_2CO$, and that the aniline had replaced both the ethoxy group of the ester and the tribromphenylimido group by phenylimido radicals.

TRIBROMACETANILID, $C_6H_2Br_3NHCOCH_3$, NH 1, Br_3 3, 4, 5.

Eight grams of the perfectly dry tribromaniline were mixed in small portions at a time with a large excess of acetic anhydride, and the dark colored solution warmed on the steam bath for a few minutes. The substance was then precipitated by pouring its solution into water, and purified by many recrystallizations from alcohol, after which it was dried at 100°, and analyzed with the following results: —

I. 0.1817 gram of the substance gave 0.2756 gram of argentic bromide by the method of Carius.

II. 0.1114 gram of the substance gave 0.1691 gram of argentic bromide.

	Calculated for $C_6H_2Br_3NHCOCH_3$.	Found.	
		I.	II.
Bromine	64.50	64.55	64.63

Properties. — This tribromacetanilid crystallizes from alcohol in white slightly radiating brushes made up of very small needles, or in globular groups of needles looking like chestnut burs. It melts at 253°–254°. The tribromacetanilid NH 1, Br_3 2, 4, 6 melts at 232° according to Remmers. Our acetanilid is soluble in benzol, and in hot alcohol, but only slightly soluble in cold alcohol; soluble with difficulty in ether or chloroform; essentially insoluble in ligroin. Sulphuric acid saponifies it only after long boiling. Fuming nitric acid converts it into the nitro compound described below.

TRIBROMNITROACETANILID, $C_6HBr_3NO_2NHCOCH_3$,
NH 1, Br_3 3, 4, 5, NO_2 2.

To prepare this substance twenty grams of the dry tribromacetanilid were added in small portions at a time to a quantity of nitric acid of specific gravity 1.50. As the reaction is vigorous, the flask must be cooled and shaken continually during the addition of the acetanilid. The solution thus obtained was poured into water, and the yellowish precipitate crystallized from a mixture of acetone and alcohol until it showed the constant melting-point 229°, when it was dried at 100°, and analyzed with the following results: —

I. 0.1485 gram of the substance gave 0.2009 gram of argentic bromide by the method of Carius.

II. 0.1624 gram of the substance gave 0.2194 gram of argentic bromide.

	Calculated for $C_6HBr_3NO_2NHCOCH_3$.	Found.	
		I.	II.
Bromine	57.55	57.55	57.49

Properties. — This tribromnitracetanilid crystallizes from alcohol and acetone in white well formed crystals belonging either to the hexagonal or orthorhombic system. When less well crystallized it forms long very slender prisms terminated by a single plane at an oblique angle, or thick clumps of curving needles. It melts at 229°; and is easily soluble in acetone; soluble in alcohol; slightly soluble in benzol or ether; essentially insoluble in ligroin. Sulphuric acid saponifies it in time, but this effect is produced much more easily by a strong solution of sodic hydrate.

TRIBROMNITRANILINE, $C_6HBr_3NO_2NH_2$, $NH_2$1, Br_3 3, 4, 5, NO_2 2.

This substance was obtained by boiling ten grams of tribromnitracetanilid with a strong solution of sodic hydrate. As the tribromnitracetanilid was saponified, the solution took on a deep reddish brown color. When the reaction was complete, the solution was acidified with acetic acid, which threw down a brownish precipitate. This was filtered out, and recrystallized from alcohol and chloroform until it showed the constant melting point 130°, when it was dried at 100°, and analyzed with the following results: —

I. 0.1912 gram of the substance gave 0.2864 gram of argentic bromide by the method of Carius.

II. 0.2006 gram of the substance gave 0.3017 gram of argentic bromide.

III. 0.2624 gram of the substance gave 18.1 c.c. of nitrogen at a temperature of 19°.4 and a pressure of 761.2 mm.

	Calculated for $C_6HBr_3NO_2NH_2$.		Found.	
		I.	II.	III.
Bromine	64.00	63.77	64.01	
Nitrogen	7.47			7.93

Properties. — This tribromnitraniline crystallizes from alcohol in yellowish orange needles arranged in radiating groups. If the cooling is rapid, little circular masses of needles are formed. It melts at 130°; and is easily soluble in alcohol, ether, benzol, or chloroform; essentially insoluble in ligroin, or in cold water, slightly soluble in boiling water.

In the hope of converting the tribromnitraniline just described into a tribromnitrobenzol, from which the vicinal tetrabrombenzol might be obtained, we submitted it to the diazo reaction as follows. Fourteen grams of the tribromnitraniline were dissolved in boiling alcohol previously acidified with sulphuric acid, and ten grams of powdered sodic nitrite added in small portions at a time. The mixture was then boiled for thirty minutes, and allowed to stand over night at ordinary temperatures. Upon adding water a yellowish precipitate was formed, which, after recrystallization from alcohol, melted at 230°. An analysis indicated that the substance was the phenol $C_6HBr_3NO_2OH$, although the agreement between the percentage of bromine found and that calculated left much to be desired. (Calculated per cent of bromine, 63.83. Found, 64.54.) Unfortunately, we did not have enough substance for more thorough purification; but its properties showed plainly that it was a phenol, as it dissolved in a solution of sodic ethylate forming a reddish brown salt, from which the original substance was recovered by acidification. As, therefore, this line of work evidently would not lead to the vicinal tetrabrombenzol, we did not think it worth while to undergo the large amount of labor necessary to prepare more of this phenol in order to characterize it more satisfactorily.

TRIBROMPHENYLURETHANE, $C_6H_2Br_3NHCOOC_2H_5$, NH 1, Br_3 2, 4, 5.

This substance was prepared in order to characterize more fully the tribromaniline NH_21, Br_3 2, 4, 5, described in our first paper.* Ten grams of the tribromaniline dissolved in benzol were heated with eight grams of chlorocarbonic ethyl ester in a flask with a return condenser, until no more hydrochloric acid was given off. The product thus obtained was crystallized from alcohol, until it showed the constant melting point 101°, when it was dried, and analyzed with the following result: —

0.1432 gram of the substance gave 0.2016 gram of argentic bromide by the method of Carius.

	Calculated for $C_6H_2Br_3NHCOOC_2H_5$.	Found.
Bromine	59.70	59.92

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* Amer. Chem. Journ., XVIII. 247.

Properties. — This tribromphenylurethane crystallizes from alcohol and water in long slender white needles in radiating bunches forming a thick felted mass. It melts at 101°; and is freely soluble in alcohol, ether, benzol, chloroform, or glacial acetic acid; insoluble in water. When it is heated with aniline it yields diphenylurea melting at 235°, and the tribromaniline, which was recognized by its peculiar odor. Its behavior, therefore, in this respect is like that of the tribromphenylurethane NH 1, Br_3 3, 4, 5, previously described in this paper.

TRIBROMNITRACETANILID, $C_6HBr_3NO_2NHCOCH_3$, NH 1, Br_3 2, 4, 5.

This substance was prepared from the corresponding acetanilid described in our previous paper.* We have not determined the position of the nitro group, but should suppose it would be ortho to the acetamido group, and therefore 6. Five grams of the tribromacetanilid were added in small portions at a time to about forty grams of nitric acid of specific gravity 1.50. The mixture was allowed to stand an hour at ordinary temperatures, and then poured into a large volume of cold water; the precipitate was recrystallized from alcohol, until it showed the constant melting point 228°, when it was dried at 100°, and analyzed with the following result: —

0.1001 gram of the substance gave 0.1348 gram of argentic bromide by the method of Carius.

	Calculated for $C_6HBr_3NO_2NHCOCH_3$.	Found.
Bromine	57.55	57.33

Properties. — This tribromnitracetanilid crystallizes from hot alcohol in little branched needles generally arranged in circular radiating groups, or in sheaves. It was pinkish white, but is probably white when perfectly pure. It melts at 228°; and is freely soluble in ether, benzol, chloroform, carbonic disulphide, or glacial acetic acid. Sulphuric acid, when boiled with it, converts it into the tribromnitraniline described below.

TRIBROMNITRANILINE, $C_6HBr_3NO_2NH_2$, $NH_2$1, Br_3 2, 4, 5.

Ten grams of the tribromnitracetanilid were heated in a flask with a return condenser with sulphuric acid diluted to the specific gravity 1.44, until the solid went into solution. The solution after it had cooled was diluted with water, neutralized with dilute sodic hydrate, and the brownish precipitate purified by recrystallization from alcohol. When it showed the constant melting point 130°, the substance was dried at 100°, and analyzed with the following result: —

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* Amer. Chem. Journ., XVIII. 249.

0.2341 gram of the substance gave 0.3513 gram of argentic bromide by the method of Carius.

	Calculated for $C_6HBr_3NO_2NH_2$.	Found.
Bromine	64.00	63.87

Properties. — This tribromnitraniline crystallizes in rather thick yellow needles often united longitudinally, and sometimes very much branched. It melts at 130°; and is very soluble in ether, benzol, chloroform, acetone, ligroin, or carbonic disulphide; soluble in alcohol; soluble with difficulty in hot water.

BEHAVIOR OF TRIBROMDINITROBENZOL (Br_3 1, 2, 4 $(NO_2)_2$ 3, 5) WITH SODIC ETHYLATE.

This reaction was described in our previous paper,* but, unfortunately, in determining the composition of the principal product we relied only on a bromine determination. On returning to the subject we realized that this was entirely insufficient to settle the nature of the body, since the ethoxy group has nearly the same molecular weight, 45, as the nitro group, 46, and therefore our bromine determination would serve equally well for a tribromresorcine (the composition which we had assigned to it, percentage of bromine 59.55), or for a tribromnitrophenetol (percentage of bromine 59.40). We accordingly prepared some more of the substance and tested for nitrogen, when to our great mortification we found that it was present, and that the substance therefore is tribromnitrophenetol, and not tribromresorcine. We regret exceedingly that our carelessness should have introduced this mistake into the chemical literature. Its composition was definitely settled by the following analyses: —

I. 0.2430 gram of the substance gave 0.3407 gram of argentic bromide by the method of Carius.

II. 0.3797 gram of the substance gave 11.9 c.c. of nitrogen at a temperature of 26° and a pressure of 766.5 mm.

	Calculated for $C_6HBr_3NO_2OC_2H_5$.	Found. I.	Found. II.
Bromine	59.40	59.67	
Nitrogen	3.47		3.51

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* Amer. Chem. Journ., XVIII. 244.

Properties of Tribromnitrophenetol. — These were given in our first paper as the properties of tribromresorcine; we therefore think it best to repeat them here under the true name. It crystallizes from alcohol in long white pearly plates terminated by two planes at an acute angle, which is usually truncated by a basal plane. It melts at 158°. It is nearly insoluble in cold alcohol, soluble in hot; soluble in chloroform, benzol, or acetone; slightly soluble in cold ligroin, more soluble in hot. The best solvent for it is hot alcohol.

In the aqueous filtrate from the tribromnitrophenetol we found the salt of a diatomic phenol melting at 67°, to which in our previous paper we assigned the formula $C_6HBr(NO_2)_2(OH)_2$, on the ground of a bromine determination. In returning to the subject we thought it well to obtain more analytical data in regard to it, and for this purpose we have made and analyzed the barium salt.

BARIUM SALT OF BROMDINITRORESORCINE(?), $C_6HBr(NO_2)_2O_2Ba$.

The constitution of the phenol has not been proved; but, as according to analogy the two hydroxyls should be in the meta position to each other, we have adopted the name given above provisionally.

The barium salt was prepared as follows. Two grams of the phenol were mixed with a freshly prepared alcoholic solution of sodic ethylate, and then treated with an aqueous solution of baric chloride. The yellow precipitate thus obtained was filtered as quickly as possible, washed three times with a little cold water, and once with ether, and then dried at 130°, and analyzed with the following result: —

0.2580 gram of the salt gave 0.1464 gram of baric sulphate.

	Calculated for $C_5HBr(NO_2)_2O_2Ba$.	Found.
Barium	33.09	33.36

This analysis, therefore, confirms our previous view of the composition of the phenol.

Properties. — The barium salt is an orange-yellow powder with no well defined crystalline form. When heated in the flame of a Bunsen lamp, it explodes. It is soluble in water, and its solubility is increased by heat; slightly soluble in alcohol; insoluble in ether, chloroform, or ligroin. Acids set free the phenol $C_6HBr(NO_2)_2(OH)_2$ from it.

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CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY.

New Series. — No. XII.

By M. L. Fernald.

I. A Systematic Study of the United States and Mexican Species of *Pectis*.

II. Some Rare and Undescribed Plants collected by Dr. Edward Palmer, at Acapulco, Mexico.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, No. XII.

By M. L. Fernald.

Presented by B. L. Robinson, 9 June, 1897.

I. — A SYSTEMATIC STUDY OF THE UNITED STATES AND MEXICAN SPECIES OF PECTIS.

The genus *Pectis* was founded by Linnæus[1] in 1758, to embrace two West Indian species, *P. ciliaris* and *P. linifolia;* the latter founded upon a plate of Sloane[2] which is well matched by the West Indian plant with corneous subulate awns. In November, 1759, Linnæus[3] gave more complete descriptions of these species, and an additional reference for *P. linifolia.*[4]

In 1762 Jacquin[5] described his *P. punctata*, which was based upon one of Plumier's figures[6] in which the leaves are represented as entire and bearing conspicuous marginal glands; while the pappus is described by Plumier[7] in the words "corona foliacea." (This figure has since been referred by De Candolle[8] to *P. Swartziana*, Less.). In 1763, in a much fuller account of the plant, Jacquin[9] describes the pappus as two setæ (" Sem. Hermaphrodita solitaria, linearia, instructa setis duabus"); and the leaves, according to the plate and the description, have cilia at their bases. Linnæus,[10] in the same year, recognized Jacquin's *P. punctata* as distinct from his own *P. linifolia,* though his distinguishing character was found only in the punctate leaves of the former. In the same work[1] Linnæus refers to *P. ciliaris* one of Plumier's figures[2] which is hardly recognizable as the West Indian and Florida species, and, as De Candolle[3] suggests, is more likely *P. Carthusianorum*. *P. minuta*, described at the same time by Linnæus,[4] is an obscure thing unless it is the *P. minuta* of Willdenow's Herbarium, referred by Lessing[5] to *P. pygmæa*, or the *P. minuta*, Schreb.,[6] which has been referred to *Bellium minutum*, L. The genus *Seala* was founded by Adanson[7] in 1763 partly upon Plumier's figure[8] which Linnæus had referred to his own *P. ciliaris*.

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[1] Syst. Nat. ed. 10, 1221.

[2] Hist. Jam. i. t. 149, f. 3 (as *Hieracium*).

[3] Amœn. Acad. v. 407.

[4] *Tagetes?* 2, Browne, Jam. 319.

[5] Enum. Pl. Carib. 28.

[6] Plum. Pl. Amer. ed. Burm. t. 86, f. 1 (as *Knautia*).

[7] l. c. 74.

[8] Prodr. v. 99.

[9] Stirp. Amer. 216, t. 128.

[10] Spec. ed. 2, 1250.

In 1788 Swartz[9] described *P. humifusa*, a West Indian plant based upon one of Plumier's descriptions and plates;[10] and three years later, in 1791, he described a *P. ciliaris*,[11] which is obviously not *P. ciliaris*, L., and which has subsequently been named by Lessing[12] *P. Swartziana*. In the same work Swartz[13] describes a *P. punctata*, not with the pappus a foliaceous crown as in Plumier's plant (De Candolle refers Plumier's plate to *P. Swartziana*), or merely of two setæ as in Jacquin's second description, but with the pappus of three *subulate* setæ; and this character, as well as the general description of the plant, seems to identify it with *P. linifolia*, L.

During the remainder of the decade three species were published, only one of which proved a good *Pectis*. *P. pinnata*, Lam.[14] (1792) has been identified with *Schkuhria abrotinoides*, as has also *P. multifida*, Orteg.[15] (1797). Cavanille's *P. prostrata*,[16] published in 1797, from Mexico, is a common species.

The first extensive consideration of the genus in this century was by

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[1] Spec. ed. 2, 1240.

[2] Plum. l. c. t. 151, f. 2.

[3] l. c. 101.

[4] Spec. ed. 2, 1250.

[5] Linnæa, vi. 713 in syn.

[6] Schreb. in Steud. Nom. ed. 1, 103.

[7] Fam. ii. 131.

[8] Plum. Pl. Amer. ed. Burm. t. 151, f. 2.

[9] Prodr. 114.

[10] *Jacobæa humifusa, Hypericifoliis*, Plum. l. c. 84, t. 95, f. 2.

[11] Swartz, Obs. 307.

[12] Linnæa, vi. 711.

[13] l. c. 308.

[14] Jour. Hist. Nat. Par. ii. 150, t. 31.

[15] Hort. Matr. Dec. 45.

[16] Cav. Ic. iv. 12, t. 324.

Poiret,[1] who discussed five of the species already mentioned (omitting *P. minuta* and *P. prostrata*) and described an additional one, *P. fasciculata*[2] from an unknown habitat. *P. pinnata*, Lam. he retained doubtfully in the genus, and *P. punctata*, Jacq. he kept distinct from *P. linifolia*, L., describing the pappus of the latter as "deux poils roides et piquans," or in the ray-akenes "trois poils très-ouverts," while the pappus of the former he describes as "deux filets sétacés"; yet apparently Poiret had not seen this species and his description was drawn directly from Jacquin.

In 1816 Lagasca founded the genus *Lorentea*,[3] distinguished generically from *Pectis* by the character, "pappus paleaceo-setaceus, paleis pluribus, inæqualibus." The original species, *L. prostrata* from Cuba, has subsequently been identified[4] with *P. humifusa*.

Cassini in 1817 described the genus *Cryptopetalon*[5] with one species, *C. ciliare* from Peru. The genus was distinguished by the "aigrette . . . composée de squamellules nombreuses, plurisériées, inégales, filiformes, fortement barbellulées, roides comme des crins, rousses, entre-griffées à la base." In the same year he founded the genus *Chthonia*[6] with one species, *C. glaucescens*. This genus Cassini distinguished from *Pectis* by its paleaceous pappus, while in true *Pectis*, he argued, the pappus is of "squamellules subtriquètres, subulées, cornées, parfaitement lisses. Ainsi, les *pectis punctata* et *linifolia* doivent demeurer dans le genre *Pectis*; mais les *pectis humifusa*, *prostrata*, et probablement le *ciliaris*, doivent entrer dans le genre *Chthonia*."

The collections made by Humboldt and Bonpland during the great scientific expedition headed by Humboldt, contained at least four species of the genus *Pectis* (of which *Chthonia* was made synonymous), and these were described in 1820.[7] The characterization of the involucre, which had formerly been described as pentaphyllous, was extended in the generic description to include forms with 8 or 10 bracts, but the pappus character was limited to aristiform pales ("Akenia linearia, triangulari-compressa, paleis compluribus aristæformibus coronata"[8]). Of the four species described two were from Mexico and two from New Granada;

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[1] Dict. v. 119-121.

[2] Poir. l. c. 120.

[3] Lag. Gen. et Sp. Nov. 28.

[4] Spreng. Syst. iii. 572.

[5] Bull. Soc. Philom. (1817) 12, & Dict. Sci. Nat. xii. (1818) 123.

[6] Bull. Soc. Philom. (1817) 33, & Dict. Sci. Nat. ix. (1817) 173, 174.

[7] HBK. Nov. Gen. & Sp. iv. 261-264.

[8] HBK. l. c. 261.

but one of the latter, *P. elongata*, with "aristis crebris (20–25), scabris, inæqualibus, patulis, rufescentibus, persistentibus, corollam et akenium æquantibus," has since been found in Mexico. *P. Bonplandiana*, with "aristis 8–10, scabris, basi paulo dilatatis, rufescentibus, corollam æquantibus," is identified with more recent specimens from Southeastern Mexico; and *P. canescens* is a species with variable pappus originally described as having the disk-akenes with "paleis 20–25, aristæformibus, scabriusculis, inæqualibus, rufescentibus, corollam vix superantibus, persistentibus," while the ray-akenes are with "squamulis nonnullis minutis subulatis." The fourth species, *P. pygmæa,* has not yet been found in North America.

In 1823 Cassini[1] discussed *Lorentea*, Lag., stating that it is undoubtedly the same as his own *Chthonia.* But, though Lagasca's genus was published some months before Cassini's, he clings to his own name, arguing, that compared with his own, Lagasca's description is inadequate. *Chthonia repens,*[2] based perhaps on *Pectis humifusa*, Swartz, and a second species, *C. leptocephala*,[3] are described; and after some speculative remarks upon the genus, Cassini says, "Nous présumons que les *Pectis pygmæa* et *Bonplandiana* sont des *Chthonia*, et que les *Pectis elongata* et *canescens* sont des *Cryptopetalon*."

In 1825 Cassini[4] discussed *Pectis,* restricting it to *P. linifolia,* L., and *P. punctata*, Jacq., and he again emphasized the distinctions he made between the genera: "Les vrais *Pectis* diffèrent essentiellement des *Chthonia* et des *Cryptopetalon*, par l'aigrette, dont les squamellules sont subtriquètres, subulées, cornées, parfaitement lisses; car les squamellules de l'aigrette des *Chthonia* sont paléiforme et dentées inférieurement, filiformes et barbellulées supérieurement; et celles des *Cryptopetalon* sont filiformes et barbellulées d'un bout à l'autre."

Torrey's *P. angustifolia*, described in 1828,[5] was the first species of *Pectis* recognized without awns, pales, or setæ. The original form with a squamellose crown is not, however, constant, for there are sometimes present one or two slender awns.

In 1830 Lessing[6] took up the name *Lorentea,* and applied it to a group very different from that of Lagasca. The characters as given by Lessing were: "Pappus disci 2-serialis, ser. ext. piliformi, brevi, interiori anguste paleacea, serrata, longa; radii nullus aut dimidiatus, coroniformis, brevis." To this genus he transferred *Pectis canescens*, at the same time describing *L. saturejoides* which differs from typical *L. canescens* chiefly in having no ray-pappus. In the same work Lessing instituted the subtribe *Pectideæ*[1] (then placed under *Vernoniaceæ*) to include *Pectis*, *Lorentea*, *Andromachia*, *Liabum*, and *Cacosmia*.

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[1] Cass. in Dict. Sci. Nat. xxvii. (1823) 202–207.
[2] Cass. l. c. 204.
[3] Cass. l. c. 206.
[4] l. c. xxxviii. (1825) 202, 203.
[5] Torr. Ann. Lyc. N. Y. ii. 214.
[6] Linnæa, v. 135.

In 1831 Lessing[2] took up critically the genera of the subtribe *Pectideæ* as he then understood it, i. e. *Pectidium*, *Pectis*, and *Lorentea*. The new genus *Pectidium* had "Pappus aristis, paucis, subulatis, planis, rigidis, corneis, basi incrassatis, lævissimis, inæqualibus, achænio brevioribus, demum divergentibus"; and the single species *Pectidium punctatum*, founded upon *Pectis punctata*, Jacq., is described as having on the disk-akenes two aristæ, on the ray-akenes three. Note that in the original generic description Linnæus says "*Pappus* aristatus,"[3] and that the characters of *Pectidium* are those ascribed by Cassini to "true *Pectis*," including *P. linifolia*, L., and *P. punctata*, Jacq. The genus *Pectis* (including *Cryptopetalon* and *Chthonia*, Cass., and *Lorentea*, Lag. not Less.) Lessing characterized by "Pappus uniserialis, serratus, aut late paleaceus, paleis 1-nerviis, semilanceolatis, in setam desinentibus, sæpe setigero-laciniatis, aut setaceo-paleaceus." In the genus as thus defined he placed *P. ciliaris*, L., *P. linifolia* [Less. not L.], *P. angustifolia*, *P. elongata*, *P. Bonplandiana*, *P. pygmæa*, and *P. prostrata*; and a number of new species, *P. Swartziana* founded upon *P. ciliaris*, Swartz,[4] in part, and four others from the West Indies. To the genus *Lorentea* he added *L. humifusa* (*Pectis humifusa*, Swartz), and a new species, *L. sessiliflora*, which we know only from South America.

In 1832 Torrey's *Pectis angustifolia* was taken up by Rafinesque[5] under the name *Helioreos*, though this name appears to have been overlooked by the subsequent authors who took up De Candolle's *Pectidopsis*.

In the Prodromus De Candolle[6] accepted, with slight modifications, the views of Lessing. He took up the original subtribe *Pectideæ* of Lessing;[7] but of his later subtribe *Pectideæ*[8] he made the division *Eupectideæ* to embrace *Pectidopsis*, *Pectidium*, *Pectis*, and *Lorentea*. Of *Pectis* an

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[1] Less. Linnæa. v. 134.

[2] l. c. vi. 706–721.

[3] L. Syst. Nat. ed. 10, 1221.

[4] Obs. 307.

[5] Atl. Jour. (1832) 145.

[6] Prodr. v. 98–103.

[7] Linnæa, v. 134.

[8] Less. l. c. vi. 706.

tifolia, Torr. he made a new genus *Pectidopsis*.[1] *Pectidium*, Lessing, was kept up, as was also his *Pectis* and *Lorentea*. *Pectis fasciculata*, Poir., which would seem a very distinct species, was reduced by De Candolle to *P. prostrata*, Cav., and six new species were described, five of them from Mexico. The genus *Lorentea* De Candolle divided into two sections, *Cryptopetalum* (for *Cryptopetalon*, Cass.), "Pappus radii paleis plurimis acuminato-setiformibus pappo disci brevioribus constans," and *Stammarium*, Willd. in Herb., "Pappus radii nullus aut dimidiatus auriculæformis brevis"; and he described five new species, *L. Hænkeana*, and *L. auricularis* (probably only a form of *Pectis canescens*, HBK.) from Mexico, and three from South America.

Hooker and Arnott,[2] in 1841, described two Mexican species, *P. Jaliscana* (printed *Taliscana*), "pappo radii et disci setis 3–6 aristatis basi dilatatis paleisque paucis brevissimis"; and *P. diffusa*, "pappi paleis setiformibus scabris inæqualibus in disco 10–20, in radio paullo paucioribus." And in the same year Torrey and Gray [3] in their Flora followed De Candolle and kept up *Pectidopsis* as a genus.

In 1844 Bentham published two Mexican species, *P. multiseta* [4] from Cape San Lucas, and *P. arenaria*,[5] in part from Acapulco. Both of these species are well represented by recent collections from the type stations. In 1846 Gardner[6] published six Brazilian *Lorenteas*, and the next year followed them with another. In 1847 J. D. Hooker[7] described two species from the Galapagos.

In 1849 Dr. Gray [8] concluded that, rather than to continue multiplying genera undistinguishable in habit and with "numerous variations and gradations" in pappus, it was necessary "to extend the character of Pectis and restore to it Pectidopsis, Pectidium, and perhaps Lorentea also." In the same work he proposed two additional subgenera, *Heteropectis* and *Pectothrix*. In the subgenus *Heteropectis*, "Pappus coroniformis et 1–4-aristatus, vel saltem fl. disci muticus; aristis serrulato-scabris," were placed *P. multiseta*, Benth., and *P. uniaristata*, DC.; and *P. fastigiata*, *P. filipes*, and *P. Coulteri* were described as new. In the subgenus *Pectothrix*, "Pappus e setis aristisve gracilibus basi vix dilatatis 6–20 (raro paucioribus) serrulato scabris vel barbellatis constans, conformis, aut fl. radii brevis auriculæformis," he placed *P. diffusa*,

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[1] DC. Prodr. l. c. 98.

[2] Bot. Beech. 296.

[3] Fl. ii. 62.

[4] Benth. Bot. Sulph. 20.

[5] Benth. l. c. 110.

[6] Hook. Lond. Jour. Bot. v. 239-241.

[7] Trans. Linn. Soc. xx. 206.

[8] Pl. Fendl. 61, 62.

Hook. & Arn., and *P. tenella*, DC. (connecting this group with *Pectis* proper); and *P. papposa* was described as new.

In 1852 Dr. Gray[1] showed that *Pectis angustifolia*, Torr. intergraded with his own *P. fastigiata*, and that with such evidence at hand both De Candolle's genus *Pectidopsis* and the species *Pectis fastigiata* were untenable. As a provisional arrangement of species Dr. Gray[2] then proposed the following: —

Pappus coroniformis, vel in disco vel in radio, et sæpius 1–4-aristatis:	
Aristis sursum scabris v. nullis. (P. angustifolia, filipes, uniaristata, et sp. nov. Am. Merid.)	PECTIDOPSIS.
Aristis corneis retrorsum hispidis. (P. Coulteri, multiseta.)	HETEROPECTIS.
Pappus uniformis, ex aristis paucis corneis lævissimis.	PECTIDIUM.
Pappus uniserialis, e paleis vel aristis basi paleaceo-dilatatis paucis.	EUPECTIS.
Pappus biserialis paleaceus, in radio nunc dimidiato-a[u]riculæformis, nunc nullus.	LORENTEA.
Pappus setosus, 1–2-serialis, setis capillaribus basi vix aut ne vix dilatatis, in radio nunc dimidiato-auriculæformis.	PECTOTHRIX.

Following the suggestion that *Lorentea* might well be united with *Pectis*, Schultz Bipontinus[3] transferred to *Pectis* the *Lorenteas* of De Candolle's Prodromus and of Hooker and Gardner, though his only new species, *P. Seemannii*, afterward proved to belong in another genus.[4]

In 1853 Dr. Gray[5] made additional notes on some of the old species, and described *P.* (*Pectothrix*) *longipes* and the anomalous *P. imberbis*. And in 1858 Triana[6] described his genus *Cheilodiscus*, "Pappus coroniformis quinquedentatus, dentibus acutis persistentibus," with only one species, *C. littoralis*, from New Granada. Apparently this belongs to the section *Pectidopsis*.

In 1861 Van Hall[7] published *P. febrifuga* from Curaçao. From the excellent plate accompanying the description, this would seem to be nearly related to *P. capillaris*. And since then a number of South American and West Indian species have been published, but these need not concern us here.

In the Genera Plantarum, Bentham and Hooker[8] suggested that further study was necessary to clear up Dr. Gray's sections *Eupectis*, *Pectothrix*, and *Lorentea*.

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[1] Pl. Wright. i. 82.

[2] l. c. 83.

[3] Bot. Voy. Herald, 309.

[4] Benth. & Hook. f. Gen. ii. 412.

[5] Pl. Wright. ii. 69, 70.

[6] Ann. Sci. Nat. ser. 4, ix. 36.

[7] Fl. Jard. Pays-Bas, iv. 33, pl.

[8] Gen. ii. 412.

In 1881 Hemsley[1] credited to Mexico 24 species of Pectis, though some of them doubtless cannot stand. *P. Liebmannii*, Sch. Bip., one of the best marked species of § *Pectothrix*, was described as new; and since the publication of Hemsley nine additional Mexican species have been described.

In 1883[2] Dr. Gray discussed the genus *Pectis*, making many critical notes upon the species. He at that time modified his division of the genus, so that he recognized only three sections: —

1. Eupectis. Pappus paucipaleaceus, vel pauci-aristatus aristis setiformibus, nunc ex aristis et paleolis paucis vel definitis constans, plerumque uniserialis.
2. Pectothrix. Pappus (saltem fl. disci) multisetosus, inæqualis, plerumque biserialis, setis interioribus validioribus quandoque aristiformibus inferne sensim latioribus nec vero paleaceis.
3. Pectidium. Pappus bi-tricornis, nempe ex aristis paucissimis (1–4) validis corneis sæpius divergentibus.

This division was followed in the Synoptical Flora,[3] where *P. Rusbyi*, Greene, from Arizona, was described as new.

Two species, *P. gibbosa* and *P. linearis*, have been published in a recent number of La Naturaleza[4] from old descriptions written by La Llave in 1832. These descriptions, however, contain so little of a specific nature that it is impossible to tell from them alone what the plants may be.

The genus *Pectis* is, as Dr. Gray has remarked, a very natural one; in fact, it presents such intergradations that it is difficult to get a really satisfactory basis for division into sections. Habital characters in such a group, with many short-lived annuals, are very unsatisfactory: in many cases plants ordinarily perennial with a suffruticose base may develop as annuals. The color of the rays, the number and length of the basal setæ of the leaves, and the distribution of glands, are all characters so inconstant as to be of only minor importance. The only character which seems sufficiently constant, at least for the larger divisions into subgenera, is in the pappus, and even that presents some obstructions to the making of clearly defined groups.

In attempting to group all the United States and Mexican species, it seems that the best results are attained by a compromise between Dr. Gray's recent treatment of the genus (Proc. Amer. Acad. xix. 43–48), and his earlier division of it in Plantæ Wrightianæ (i. 83). The subgenus *Heteropectis* is sufficiently unique, apparently, in its retrorsely barbed awns and low diffuse habit to separate it from the erect entire-leaved species of § *Pectidium* with smooth awns. The subgenus *Eupectis*, too, as recently defined by Dr. Gray, seems to contain two well marked groups, and therefore essentially the distinctions made by him in Plantæ Wrightianæ have been adopted : § *Eupectis*, with definitely paleaceous pappus, and § *Pectidopsis*, with a few slender but rather rigid aristæ. The subgenus *Pectothrix* has been taken up as defined by Dr. Gray in the Proceedings of the American Academy, it being impossible to find any satisfactory character to distinguish the old and confused § *Lorentea*.

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[1] Biol. Centr.-Am. Bot. ii. 224–227.

[2] Proc. Am. Acad. xix. 43–48.

[3] Gray, Syn. Fl. i. pt. 1, 360.

[4] La Nat. vii. Append. 84.

As suggested before, these groups are not constant in their characters. But with the exception of a few cases, they are fairly well marked. Some forms of § *Eupectis* (*P. Berlandieri* and *Sinaloensis*) may have the pales rarely deciduous from the bases of slender awns, thus assuming the characters of § *Pectidopsis*. Other species (*P. arenaria* and *bracteata*) have in addition to definite pales some slender setæ, in this making a close approach to members of § *Pectothrix* (*P. Hænkeana*, *longipes*, *canescens*, &c.) with a few stout elongated setæ. In § *Pectidopsis* and § *Pectothrix* the pappus in either the disk or ray, or in both, may be reduced, and in such cases species, ordinarily well marked, may be confused. For instance, there are rarely such specimens of *P. papposa* with subfastigiate heads hardly to be distinguished from similar forms of *P. angustifolia*. In some species, too, of § *Pectidopsis* (*P. filipes* and *capillaris* for example), the pappus, either in the disk or ray, consists of rather stout smooth awns suggesting those of § *Pectidium*. In § *Pectothrix* the bristles are normally more than 10, but in *P. elongata* and *diffusa* they may become reduced in number and more or less dilated below, as in species of § *Pectidopsis* (*P. Berlandieri*, &c.). Species of § *Heteropectis* generally show little tendency to run into the other subgenera, but the disk-pappus in two species, *P. multiseta* and *ambigua*, is reduced. And in the apparently well-marked § *Pectidium* the pappus of *P. imberbis* may sometimes have, in addition to the rigid awns, a few paleaceous awns not unlike forms in § *Eupectis ;* or the pappus may be entirely obsolete, as in the other subgenera.

PECTIS, L. Rather low branching mostly aromatic or heavy-scented herbs with opposite connate generally glandular-dotted leaves mostly with a few basal setæ, rarely setiferous to the tip, or even naked: heads small or middle-sized, mostly radiate, sessile or on bracteate peduncles, solitary or subcorymbose : involucre cylindrical or campanulate, naked at the base, of a single series of equal free generally glandular-dotted carinate and often involute bracts, more or less conduplicate about the akene: receptacle naked: ray-flowers fertile, the rays yellow, rarely purple or white; disk-flowers perfect, the corolla 5-lobed, more or less bilabiate: style hispidulous, the short branches obtuse and without appendages: pappus of a few or many pales or awns or bristles, or reduced to squamellæ or to an auriculiform crown, or rarely wanting: akenes linear, terete or somewhat angled, generally pubescent, becoming glabrate. — Syst. Nat. ed. 10, 1221, Amœn. Acad. v. 407 & Gen. ed. 6, no. 963; Poir. Dict. v. 119; HBK. Nov. Gen. & Spec. iv. 261; Cass. in Dict. Sci. Nat. xxxviii. 202; Less. Linnæa, vi. 708; DC. Prodr. v. 98; Gray, Pl. Fendl. 61, Pl. Wright. i. 82, & Proc. Am. Acad. xix. 43; Benth. & Hook. f. Gen. ii. 412; Hemsley, Biol. Centr.-Am. Bot. ii. 224; Baker in Mart. Fl. Bras. vi. pt. 3, 285; Engl. & Prantl, Nat. Pflanzf. iv. Ab. 5, 266. *Seala*, Adans. Fam. ii. 131. *Lorentea*, Lag. Gen. et Spec. Nov. 28; Less. Linnæa, v. 135; DC. Prodr. v. 101. *Stammarium*, Willd. in Less. l. c. in syn.; DC. Prodr. v. 102, as section. *Cryptopetalon*, Cass. Bull. Soc. Philom. jan. 1817 & Dict. Sci. Nat. xii. 123. *Chthonia*, Cass. Bull. Soc. Philom. (1817) 33 & Dict. Sci. Nat. ix. 173. *Pectidium*, Less. Linnæa, vi. 706; DC. Prodr. v. 98. *Helioreos*, Raf. Atl. Jour. (1832) 145. *Pectidopsis*, DC. Prodr. v. 98; Torr. & Gr. Fl. ii. 62. *Cryptopetalum*, DC. l. c. 101, in syn. *Cheilodiscus*, Triana, Ann. Sci. Nat. ser. 4, ix. 36.

§ 1. Eupectis, Gray. Pappus (at least of disk) of comparatively large pales with or without terminal awns, or in one section with the pales often splitting away from the bases of the awns: involucre of 4 to 10 bracts. — Pl. Wright. i. 83 & Proc. Amer. Acad. xix. 44, in part. *Seala*, Adans. Fam. ii. 131. *Lorentea*, Lag. Gen. et Sp. Nov. 28; Gray, Pl. Wright. i. 83, in part. *Chthonia*, Cassini, Bull. Soc. Philom. (1817) 33, & Dict. Sci. Nat. ix. 173. *Pectis*, Less. Linnæa, vi. 708, in part; DC. Prodr. v. 98, in part.

* Pales few (4 to 6 in disk, 2 or 3 in ray).

+ Pales all attenuate or prolonged into awns or subulate tips.

++ Erect or diffuse, involucre 4–6 (usually 5)-bracteate: awns of the pappus with permanent paleaceous bases.

P. ciliaris, L. Slender, erect and sparingly branched or diffuse, 1 to 4 dm. high, the somewhat tetragonous stems smooth or sparingly puberulent above: leaves linear or linear-oblanceolate, acutish, 3 cm. or less in length, with 2 lines of large glands beneath and rarely a few irregularly scattered smaller ones; margins entire or closely serrulate, becoming revolute, bearing from 3 to 6 pairs of remote setæ well below the middle: heads solitary or in 2's or 3's, sessile or subsessile in the axils of the leaves or on short leafy branches: involucre 5 to 6 mm. high, 10–15-flowered; the 5 linear-oblong bracts acutish, strongly conduplicate, keeled toward the bases, ciliate, bearing a few large glands especially toward the tips: rays narrow, 2 or 3 mm. long: pales subequal, the longest 1½ or 2 mm. long, lance-attenuate with a serrulate tip or with a lanceolate or lance-ovate fimbriate base tapering gradually to a serrulate awn; in the disk-pappus 1 or 2 shorter intermediate pales often present: akenes sparingly appressed-pubescent, 3 mm. long. — Syst. Nat. ed. 10, 1221, Amœn. Acad. v. 407, & Spec. ed. 2, 1250. *P. anceps*, Less. Linnæa, vi. 715, and *P. costata*, Ser. & Merc. in DC. Prodr. v. 100 *fide* Grisebach. *P. ciliata*, Steud. Nom. ed. 2, i. 360, in syn. *fide* Hook. f. & Jack. Ind. Kew. ii. 443. *Chthonia glaucescens*, Cass. in Dict. Sci. Nat. ix. 173, and *C. ciliaris*, Cass. l. c. xxvii. 206 *fide* Steud. l. c. (reduced to *Pectis ciliata*, doubtless a misprint for *P. ciliaris*) and *fide* Hook. f. & Jack. l. c. i. 532. — FLORIDA, Charlotte Harbor (Blodgett), Miami (Garber), Lastero Bay (Garber, no. 14), Tampa (Nash. no. 2479), Keys of Caximbas *fide* Chapman. Also in the West Indies.

P. Lessingii. More diffusely branched and more leafy than the last: leaves similar, but narrower, mucronulate, with 2 distinct rows of marginal glands: heads solitary on sparingly bracteate filiform peduncles 2 or 3 cm. long: bracts of involucre less conduplicate than in the last, the glands fewer or wanting: pappus more abruptly awned, or sometimes awnless: akenes spreading-pubescent or glabrate. — *P. linifolia*, Less. Linnæa, vi. 709 (excl. syn.), not L.; DC. l. c. 99 (excl. syn.); Griseb. Fl. Brit. W. I. 378; Gray, Syn. Fl. i. pt. 2, 360. — FLORIDA, Key West (Blodgett, Chapman), Palm Cape (Chapman), Miami (Garber), Cape Sable (Garber, no. 22, Simpson, no. 170), between Everglades and Biscayne Bay (Curtis, no. 1162). Also in the West Indies. A single anomalous specimen from Key West (Blodgett) has some of the leaves mucronulate and the solitary head subsessile, thus suggesting the preceding species.

++ ++ Depressed annuals: heads sessile or subsessile, with inconspicuous rays: pales subequal, lance- or linear-attenuate, sometimes awn-tipped.

= Pappus simply of attenuate pales, in the disk 5 or 6, in the ray 2 or 3.

P. prostrata, Cav. Stems prostrate, forming mats sometimes 4 dm. across (rarely simple and ascending), smooth or puberulent in lines: leaves oblanceolate or spatulate-linear, blunt or mucronate, 3½ cm. or less in length, 2 to 5 mm. broad, with many fine punctate dots on the pale lower surfaces; margins entire or closely serrulate, slightly revolute, with 5 to 9 pairs of setæ mostly below the middle: heads solitary or in small terminal or axillary clusters: involucre oblong, 5 to 7 mm. high, 3 or 4 mm. broad, 9–25-flowered; bracts 5, oblong, blunt, with scarious margins and prominent thickened keels: pales sparingly serrulate, 2 to 2½ mm. long: akenes spreading-hirsute or glabrate, 3½ to 4 mm. long. — Ic. iv. 12, t. 324; Less. Linnæa, vi. 714; DC. Prodr. v. 100. *Chthonia prostrata*, Cass. Dict. Sci. Nat. ix. 173. — A common and polymorphous species, the typical form growing from the Southwestern United States to Yucatan and Guatemala. ARIZONA, near Camp Grant (Rothrock, no. 722), sandy plains near Mexican boundary (Pringle); NEW MEXICO (C. Wright, nos. 245, 1123); SONORA (Thurber, no. 971), Alamos (Palmer, 1890, no. 659); DURANGO (Palmer, 1896, no. 512); SAN LUIS POTOSI (Parry & Palmer, no. 361); OAXACA (Nelson, no. 1693); YUCATAN (Schott, no. 533, Gaumer, nos. 788, 1092); GUATEMALA, Santa Rosa (Heyde & Lux in John Donnell Smith's Exsic., no. 3366^b), Canchón (Heyde & Lux, no. 6154). A puzzling form with narrow heads and leaves setiferous to the tip has been collected in Guatemala (Heyde & Lux, no. 4232).

Var. **cylindrica.** Leaves generally rounded at the tips, rarely mucronate; setæ fewer, 2 to 5 pairs near the base: heads generally solitary (in one specimen clustered): involucre longer and narrower, 8 or 9 mm. high, 2 or 3 mm. broad; bracts 3, thin, plane or a little conduplicate, finely canaliculate, the mid-vein slightly or scarcely thickened into a keel: akene and pappus a third longer than in the type. — Southwestern United States and adjacent Mexico. ARIZONA (Palmer, 1867, no. 128), Apache Pass (Lemmon, no. 619); NEW MEXICO (Palmer); COAHUILA, Monclova (Palmer, 1880, no. 640); SONORA, Guaymas (Palmer, 1887, no. 145).

Var. **urceolata.** Ferruginous-pubescent on the stems, midribs, and involucres: leaves large, the larger 3½ cm. long, 6 mm. wide, with 8 to 12 pairs of setæ: involucre urceolate, 9 or 10 mm. high; the 5 thick bracts with broad rounded pubescent keels. — CHIHUAHUA, Hacienda San José (Palmer, 1885, no. 53).

= = Pappus a row of linear-attenuate setulose pales, with a minute exterior setulose crown at the base; pales the same number both in the disk and in the ray.

P. Schaffneri, Schz. Bip. Very low and slender, 5 cm. or so high: stems puberulent: leaves linear-attenuate, cuspidate, 1⅓ to 2½ cm. long, 1 to 1⅔ mm. wide, margins entire or minutely serrulate, becoming entire:

involucre oblong-lanceolate, 6 mm. high, 8–9-flowered, of 3 or 4 oblong acute nerveless conduplicate but scarcely keeled bracts: pales 3½ or 4 mm. long, slightly exceeding the akenes. — Schz. Bip. in Gray, Proc. Am. Acad. xix. 45. — MEXICO, Valley of Mexico (Schaffner, no. 84).

++ ++ ++ Erect or diffuse: involucre 7–10-bracteate: pappus rufescent, the laciniate paleaceous bases often splitting away from the setulose awns.

P. Bonplandiana, HBK. Slender, erect or diffuse, dichotomously branched: the branches smooth or sparingly pubescent, 2 dm. or less in height: leaves linear-lanceolate, mucronate, entire or minutely serrulate toward the apex, 1 to 2½ cm. long, 1 to 3 mm. wide, irregularly dotted beneath, with 1 or 3 pairs of basal setæ: heads terminal or axillary, solitary on slender 4–5 bracteate peduncles 2 or 3 cm. long: involucre 4 to 4½ mm. high, about 20-flowered; bracts linear-oblanceolate, acutish or blunt, conduplicate, minutely puberulent at the tips, keeled from above the middle and bearing a few large glands: rays narrow, 2 mm. long: awns of pappus subequal, the longest 2 mm. in length, in the disk 5 or 6, in the ray 2, the lanceolate pales slightly laciniate: akenes puberulent, 3 mm. long. — Nov. Gen. & Spec. iv. 263; Less. Linnæa, vi. 712; DC. Prodr. v. 99; Gray, Proc. Am. Acad. xix. 46. *P. linearis*, Willd. in Less. l. c. in syn. *P. Seemanni*, Gray, l. c. v. 181, not Schz. Bip. — Eastern Mexico. TAMAULIPAS, Tampico *fide* DC. l. c.; QUERETARO, near Queretaro (Humboldt & Bonpland in HBK. l. c.); VERA CRUZ, Wartenberg near Tantoyuca (Ervendberg, no. 137), Mirador (Liebmann, no. 395).

P. Sinaloensis. Diffuse, the branches smooth or hirtellous, ½ to 4 dm. long: leaves oblanceolate or obovate-oblong, mucronate, entire, 2 cm. or less long, 2 to 8 mm. wide, sparingly dotted on the pale lower surfaces, naked or with 1 or 2 pairs of setæ: heads much as in the last but larger, on 4–7-bracteate peduncles 3 to 6 cm. (rarely 2½ cm.) long: involucre 4 to 5½ mm. high, 30–40-flowered; bracts more pubescent at the tips: rays 4 or 5 mm. long: pappus much as in the last, 3½ to 4 mm. long, the pales more deeply laciniate: akenes sparingly appressed-pubescent or glabrate, hardly equalling the pappus. — On dry hills, Northwestern Mexico, December and January. SINALOA, Mazatlan (W. G. Wright, no. 1204, F. H. Lamb, no 313). A specimen collected by Seemann (without locality) belongs here, as probably does his no. 1490 from Mazatlan, cited by Hemsley under *P. Bonplandiana*.

+ + Pales elliptic, mostly obtuse.

P. Swartziana, Less. Annual, erect, trichotomous above, slender, smooth, about 3 dm. high: leaves lanceolate or oblong-linear, obtuse or acute, about 12 mm. long, 2 to 4 mm. wide, with 2 rows of large glands; margins scabrous, naked or with 1 or 2 pairs of basal setæ: heads about 5 or 6 mm. high, 10–12-flowered, on elongated peduncles: involucre cylindric, 5–8-bracteate, the conduplicate bracts obtuse and with scarious margins: pappus of short equal pales, or with one of them longer, lance-attenuate and serrulate. — Linnæa, vi. 711; DC. Prodr. v. 99 (Plum. Pl. Amer. ed. Burm. t. 86, f. 1). *P. patula*, L. f. in herb. *fide* DC. l. c. in syn. *P. punctata*, Swartz in herb. L'Her. *fide* DC. l. c. in syn. *P. ciliaris*, Swartz, Obs. 307, not L. — PANAMA, hills around Loseria (S. Hayes, no. 690 *fide* Hemsley); also in Jamaica and Hayti. Plant unknown to us, the description drawn from Lessing and De Candolle.

* * Pales many (10 to 20) at least in the disk.

+– Stems more or less spreading or decumbent: leaves broadly linear.

P. arenaria, Benth. A prostrate perennial, the smooth, thick stems creeping extensively and forming mats, sending up many short branches with rosettes of leaves: leaves linear or spatulate-linear, 1 to 4 cm. long, 3 to 6 mm. wide, rounded at the tips and mucronate, pale beneath, obscurely but closely pellucid-punctate, with a single marginal row of dark glands; margins revolute, entire, with 3 to 7 pairs of basal setæ: peduncles erect or curving, 1 to 7 cm. long, compressed, angulate and almost winged above, with 2 to 7 prominent lance-subulate bracts 6 mm. long: involucre broadly cylindrical or campanulate, 8 to 12 mm. high, 5 to 8 mm. broad, 20–90-flowered; bracts 5 to 8, flat, imbricate, from lanceolate to ovate-oblong, 2 to 6 mm. wide, obtuse or acutish, many striate, slightly keeled below the middle and tapering to conspicuously thickened bases, sometimes sparingly ciliate: rays lanceolate to ovate-oblong, 6 or 7 mm. long: pappus sordid; in the disk of 10 to 20 linear-subulate very unequal setiferous pales, 4 to 6 of them longer (4 mm. long) and more dilated below than the others; in the ray shorter and usually fewer pales: akenes compressed, 6 or 7 mm. long, smooth and glossy or sparingly short-setose. — Bot. Voy. Sulph. 110. The synonymy of this species is very confused, and, from the descriptions, it is difficult to make it out. *Lorentea multiflosculosa*, DC. was described in the Prodromus (v. 102) from Peru, and from the description seems to be a form of *Pectis canescens*, HBK. The name, however, was soon changed by Schultz Bipontinus to *Pectis multiflosculosa* (Schz. Bip. in Seem. Bot. Voy. Herald, 309), but according to Bentham and Hooker f. (Gen. ii. 412) *P. multiflosculosa*, Schz. Bip. in herb. is the same as *P. arenaria*, Benth. Since then, however, Klatt (Leopoldina, xx. 92) has founded upon *P. multiflos-*

culosa, Schz. Bip., not *Lorentea multiflosculosa*, DC., a new species, *P. bibracteata.* With no authentic specimens at hand of the plants of either Schultz or Klatt the synonymy must still remain confused. The foregoing description of *P. arenaria* is drawn in part from material which has been kindly compared by Mr. Thiselton-Dyer with Bentham's type.— Prostrate in the sands of the Pacific coast of Mexico and Central America. SINALOA, Mazatlan (F. H. Lamb, no. 971); COLIMA, Manzanillo (Palmer, 1890, no. 971); GUERRERO, Acapulco (Barclay *fide* Benth., Palmer, 1891, no. 481); SAN SALVADOR, Conchagua (Œrsted *fide* Benth.). Also in Ecuador and Peru.

P. grandiflora, Klatt. Stem herbaceous, glabrous, branching; branches leafy even to the apex, monocephalous: leaves opposite, linear, mucronate, 2 cm. long, 2 mm. wide, densely glandular-punctate, with 6 pairs of setæ: peduncles terminal, 2½ cm. long, curving, angulate, almost winged, with 2 median bracts: involucre campanulate, 1 cm. long, equally broad, 40-flowered; the 5 bracts broad-ovate, 6 mm. wide, many-striate, keeled, densely ciliate: rays lanceolate, 5 mm. long, 1½ mm. wide, reddish: pales 14, scabrous, unequal, yellowish: akenes elongate, 6 mm. long, short-setose.— Klatt, Botanisch. Beibl. z. Leopoldina, 1895 (comp. nov. Costaric.), 6.— COSTA RICA, "Vers la buche du Hâto-Viejo, versant du Pacifique, leg. janv. 1893" (Pittier, no. 7342). A species unknown to us, the foregoing description, translated from Klatt, in many ways suggesting *P. arenaria*, Benth.

P. depressa. A depressed annual, forming mats sometimes 3 or 4 dm. across: stems villous, very branching: leaves linear-oblong, 1 to 2 cm. long, 1½ to 5 mm. wide, mucronate, ciliate, with 3 to 5 pairs of basal setæ, beneath densely punctate and with slightly villous midribs: heads solitary on terminal and axillary filiform 3–4-bracteate peduncles about 2 cm. long: involucre companulate, 4 or 5 mm. high, 3 or 4 mm. broad, 35–40-flowered; the 5 unequal oblong obtuse bracts thin, ciliate and minutely punctate: rays oblong, yellow, 3 mm. long: disk-pappus of 10 or 12 linear-subulate unequal setulose pales and 3 or 4 longer ones, 2 mm. long; ray-pappus generally reduced to a short irregular crown of more or less confluent pales: akenes 2 mm. long, short-setose.— GUERRERO, very common in moist exposed places, Acapulco (Palmer, 1894, no. 16).

+— +— Stems erect: leaves crowded, filiform.

P. bracteata, Watson. Perennial with a slender branching caudex: stems smooth, angulate, 2 or 3 dm. high, densely leafy toward the base, passing into many-bracteate long peduncles: leaves almost or quite filiform, 2 to 6 cm. long, with conspicuous subulate tips and 2 rows of dark glands, entire or rarely with 1 or 2 small lobes, but no setæ at the bases: peduncles elongate, 1½ to 2 dm. long, with many bracts, the lower bracts leaf-like, the upper reduced: heads large, 1 cm. or so high, almost as broad, 60–80-flowered; involucre of 8 to 15 oblong bracts thickened and herbaceous below, with conspicuous dark glands, scarious above, with round or subtruncate erose tips: rays oblong, 1 cm. long, white, becoming dark-striped with age: pappus sordid, of 10 to 20 subequal linear-subulate setiferous pales, a few of them setiform and hardly paleaceous below, 4½ or 5 mm. long, equalling the glabrate akenes. — Proc. Am. Acad. xxv. 155. — COAHUILA, calcareous hills, Carneros Pass (Pringle, no. 2403). Originally placed by Dr. Watson in § *Pectothrix*, but the definitely paleaceous pappus, strongly resembling that of *P. Sinaloensis*, places it rather in this section.

§ 2. PECTIDOPSIS, Gray. Annuals, or rarely perennials (?) with narrow leaves setiferous at the bases: involucre short-cylindrical, the bracts linear, often becoming strongly involute: pappus of a few (1 to 6) slender upwardly scabrous setiform rather rigid awns sometimes dilated at the bases, with or without a short crown of separate or united squamellæ, or sometimes reduced merely to the crown. — Pl. Wright. i. 82. *Helioreos*, Raf. Atl. Jour. (1832) 145. *Pectidopsis*, DC. Prodr. v. 98. *Pectis* § *Eupectis*, Gray, Proc. Am. Acad. xix. 44, in part.

* Low branching herbs with elongate-linear leaves: heads subsessile or short-peduncled, fastigiate: involucre about 8-bracteate. (Forms of *P. papposa* may be looked for here.)

P. tenella, DC. Low, 2 dm. or less high, spreading and branching from near the base: stems angulate, smooth or minutely puberulous: leaves mucronate, 1½ to 4 cm. long, 1 or 2 mm. wide, broadened at the bases, with prominent midribs and 2 rows of large glands on the lower sides; margins revolute, with 1 to 4 pairs of setæ at the bases: involucre 4 or 5 mm. high, 15–25-flowered; the bracts prominently keeled, with scarious margins, bearing toward the tips a large gland, and sometimes 1 or 2 below: rays oblong, 3½ to 5 mm. long, yellow: pappus merely of 2 to 6 slender variously unequal awns, the longest 2 to 4 mm. long: akenes slightly longer than the pappus, smooth or minutely short-setulose. — Prodr. v. 99; Gray in Torr. Bot. Mex. Bound. 73 & Proc. Amer. Acad. xix. 46. Plains, Southern Texas to Chihuahua and Tamaulipas. TEXAS, Laredo, and between the Rio Grande and the Nueces (Berlandier, nos. 599, 985, 2009, 2415), Rio Coleto (Thurber, no. 19); CHIHUAHUA, Chihuahua (Pringle, no. 648); TAMAULIPAS, near Mier (Gregg, no. 62).

P. angustifolia, Torr. Plant very aromatic, resembling *P. tenella:* pappus a shallow cup or crown of 4 or 5 more or less connate squamellæ. — Ann. Lyc. N. Y. ii. 214; Gray, Pl. Fendl. 61 & Gray in Torr. Bot. Mex. Bound. 73; Hook. Bot. Mag. ciii. t. 6286. *Helioreos*, Raf. l. c. *Pectidopsis angustifolia*, DC. Prodr. v. 98; Torr. & Gr. Fl. ii. 62. — Dry soil, KANSAS (Plank) and COLORADO (Parry, &c.) to LOWER CALIFORNIA (Palmer, 1887, no. 657) and CHIHUAHUA (Hartman, no. 817).

Var. subaristata, Gray. Pappus, in addition to the crown, of 2 slender awns. — Pl. Wright. i. 82. *P. fastigiata*, Gray, Pl. Fendl. 62. *P. angustifolia*, Gray, Proc. Am. Acad. xix. 46, in part, not Torr. — Southern Texas and New Mexico to San Luis Potosi. TEXAS, near Austin (Chas. Wright), between the Pecos and the Limpia (Chas. Wright, no. 244), Georgetown (Palmer, 1880, no. 703); NEW MEXICO, Deming (Kellogg); COAHUILA, Saltillo and Monclova (Palmer, 1880, nos. 701, 702); SAN LUIS POTOSI (Parry, no. 519), near Peotillos (Schaffner, no. 325).

* * Erect, branching above, heads short-pedunculate in cymose or glomerate inflorescences: involucre 3–5-bracteate: awns slightly dilated at bases. (Forms of *P. elongata* may be looked for here.)

P. fasciculiflora, DC. Stems erect from a slightly suffruticose base, smooth, 3 to 5 dm. high, branching mostly toward the summit: leaves linear-oblanceolate, obtuse or acute, sometimes mucronate, the largest 3½ cm. long, 6 mm. wide, faintly pellucid-punctate, entire, or closely serrulate, with 1 to 5 pairs of setæ toward the bases, or the lowest leaves rarely naked: heads crowded on short branches in the axils of the reduced floral leaves: involucre 4 to 6 mm. high, 8–12-flowered; bracts linear, acuminate, keeled below the middle: rays oblong, 3 mm. long: pappus 1 to 3 very slender awns 4 or 5 mm. long, with or without a shallow irregular squamellose cup at the base: akenes minutely setulose or glabrate, half as long as the pappus. — Prodr. v. 100. — Southwestern Mexico, first collected by Hænke. GUERRERO, San Marcos (Nelson, no. 2268). A little known species apparently well represented by Mr. Nelson's plant.

P. fasciculata, Poir. With the habit of the former: the leaves "ovales, lancéolées, élargies": the involucral bracts oblong, obtuse, and the pappus "une membrane qui supporte latéralement deux filets soyeux." — Dict. v. 120. — A plant, judging from the description, very near if not quite *P. fasciculiflora*, though placed by De Candolle in *P. prostrata*.

P. Berlandieri, DC. A low annual. 1 or 2 dm. high, of bushy habit, with many angulate smooth or minutely puberulent ascending branches: leaves linear, the largest 3 cm. long, acuminate, sometimes mucronate, scabrous, with 2 to 4 pairs of setæ toward the bases: heads in an open leafy cyme, or glomerate: involucre 5 mm. high, about 12-flowered; the 5 linear acuminate bracts strongly conduplicate and slightly keeled toward the bases: rays narrow, 2 mm. long: pappus of subequal slender awns, 3½ to 5 mm. long; in the disk 5 or 6 (rarely 7), in the ray 2 or 3: akenes 2½ to 3½ mm. long, minutely short-setose or glabrate. — Prodr. v. 100; Gray, Proc. Am. Acad. xix. 46. — Eastern Mexico, near the coast. TAMAULIPAS, San Fernando (Berlandier, nos. 1537, 3037), near Tampico (Palmer, 1879, no. 1096); VERA CRUZ, between Tantoyuca and Tampico (Berlandier, no. 732), near Tantoyuca (Berlandier, no. 2152).

* * * Erect, simple or branching mostly above the base, stems purplish: leaves linear or lanceolate, the glands scattered or in lines between midrib and margins: heads scattered or solitary on long slender peduncles (2 or more times as long as the head): involucral bracts about 5, acute or acuminate, purplish: rays yellow or purplish. (Forms of *P. diffusa* may be looked for here.)

+– Awns obviously dilated at the base.

P. capillaris, DC. Erect smooth or minutely pubescent annuals, 1 or 2 dm. high, with slender subtetragonous stems diffusely branching above: leaves linear, mucronate, the larger 3 cm. long, 3 mm. wide, above scabridulous, beneath with prominent midribs and two rows of large glands about midway between the margins and midribs; margins with 2 to 5 pairs of setæ below the middle: peduncles many, terminal and from the upper axils, capillary, 2 or 3 cm. long, 2–4-bracteate: involucres 4 to 6 mm. high, 10–15-flowered: rays oblong, 2 mm. long: pappus 2 to 6 (or even 1) slender awns 4 or 5 mm. long, with or without a few squamellæ at the bases: akenes hardly equalling the pappus, appressed short-setose or glabrate. — Prodr. v. 99. *P. Jaliscana* (printed *Taliscana*), Hook. & Arn. Bot. Beech. Voy. 296; Hemsley, Biol. Centr. — Am. Bot. ii. 225, in part; Gray, Proc. Am. Acad. xix. 46; Klatt, Leopoldina, xx. 91 (reprint 4). — Southwestern Mexico. JALISCO, Jalisco (Beechy *fide* Hook. & Arn.), Rio Blanco (Palmer, 1886, no. 760), Plains of Guadalajara (Pringle, no. 1813, in part); OAXACA, near Las Bacas, *fide* DC. l. c. There is little doubt that *P. Jaliscana*, described from incomplete material, is the same as De Candolle's plant. *P. Jaliscana* was based upon a form with squamellæ at the base of the awns, but in Palmer's Rio Blanco plants akenes with and without squamellæ are found on the same individual.

Var. paucicapitata. Slender, with a few elongated ascending branches: leaves variable in size, the largest 5 cm. long, 5 mm. wide, with 4 or 6 rows of glands (only 2 rows on the small leaves); margins with 5 to 9 pairs of setæ: peduncles very few and scattered, capillary, 1 or 2 cm. long, 1–3-bracteate, involucre 5 mm. long, about 10-flowered: pappus of 2 or 3 setiform awns barely as long as the akene. — *P. Berlandieri*, DC.? var. *Palmeri*, Gray, Proc. Am. Acad. xxi. 393. — CHIHUAHUA, south of Batopilas (Palmer, 1885, no. 61).

+ + Awns slightly or not at all dilated at the base.

P. uniaristata, DC. Stems compressed-angulate, smooth or roughish below the nodes, very diffusely branched from below the middle, 1 to 3 dm. high: leaves mucronate, scabrous above, with 2 or 4 rows of glands beneath, bearing 3 to 5 pairs of setæ; the cauline leaves about an inch long, the others becoming reduced to small bracts: peduncles slender, 8 to 13 mm. long, 1–3-bracteate: involucre 4 or 5 mm. high, about 10-flowered: pappus a shallow cupuliform crown and 1 or 2 (rarely 0) very slender setiform awns, 2 mm. long: akenes equalling the pappus, appressed short-setose. — Prodr. v. 99; Gray, Proc. Am. Acad. xix. 46. — Mexico *fide* DC. l. c.; JALISCO, plains of Guadalajara (Pringle, no. 1813, in part); COLIMA, Manzanillo (Xantus). Both plants which have been examined have the stems distinctly angulate, not "terete" as in De Candolle's characterization; but otherwise they conform closely to his description.

+ + + Awns none, pappus merely a squamellose cup.

P. dichotoma, Klatt. Erect or suberect, 8 to 15 mm. high, glabrous, somewhat dichotomous-branching: leaves spatulate-linear, submucronate, the largest about 2 cm. long, 2 mm. wide, with 2 or 4 rows of glands beneath, and bearing 2 to 4 pairs of setæ: peduncles capillary, 1½ cm. long, naked or with 1 or 2 bracts: involucre 3 or 4 mm. high, 8–10-flowered: cupuliform pappus slightly longer than in *P. uniaristata*: akenes short-setose or glabrate. — Leopoldina, xx. 92 (reprint 5). *P. filipes*, Sch. Bip. in herb., not Harv. & Gray. *P. Jaliscana*, Hemsley, Biol. Centr.-Am. Bot. 225, in part, not Hook. & Arn. *P. uniaristata*, DC., var. *holostemma*, Gray, Proc. Am. Acad. xix. 46. — Mexico, at Consoquitlo (Liebmann, no. 394).

* * * * Branching mostly from the base, often very diffuse: leaves linear with large scattered marginal glands: heads scattered or more or less clustered, on elongated capillary peduncles: involucral bracts 5 to 8, obtuse or acutish.

+ Involucre 5-bracteate: awns obviously dilated at the base.

P. filipes, Harv. & Gray. Very slender (or the stem rarely becoming stout), 1 to 5 dm. high; the diffuse branches smooth and shining or scabrous, the internodes elongated: leaves plane or revolute, smooth or scabrous toward the bases, obtuse or acute and sometimes mucronulate, shorter than or equalling the internodes, in large specimens 5 or 6 cm. long, 3 mm. wide, naked or bearing 1 to 5 pairs of basal setæ: peduncles terete, 2 to 8 cm. long, ebracteate or with 1 to 3 remote bracts: involucre 4 to 6 mm. high, about 10-flowered, the bracts blunt or quite obtuse, plane or slightly keeled below the middle, generally glandless or with faint glands: rays 5 or 6 mm. long: pappus 1 to 4 slender rigid awns 2½ to 4 mm. long, and sometimes a few blunt squamellæ at the base: akenes 4 or 5 mm. long. — Harv. & Gray in Gray, Pl. Fendl. 62; Gray, Pl. Wright. ii. 69, in Torr. Mex. Bound. 73 & Bot. Cal. i. 400. *P. Jaliscana*, Hemsley, Biol. Centr.-Am. Bot. ii. 225, in part, not Hook. & Arn. *P. punctata*, Wats. Proc. Am. Acad. xxiv. 58, not Jacq. — A lemon-scented species common in the mountains from Southwestern Texas through New Mexico, Arizona, and adjacent Mexico. TEXAS, Pena Colorado (Havard, no. 11); NEW MEXICO, Coppermine Creek (C. Wright, no. 1125), Coke Cañon (Thurber, no. 1167); ARIZONA, Sulphur Springs (Rothrock, no. 539), near Fort Huachuca (Lemmon, no. 2781), Santa Rita Mts. (Pringle); SONORA, Guaymas (Palmer, 1887, no. 656). Founded upon Coulter's no. 329 from "California."

Var. subnuda. Suberect, branching mostly above the base: peduncles 1½ to 3 cm. long, ebracteate or with one or two apical bracts: involucre pale, purple-tinged, 5 mm. high, the bracts acutish or rarely obtuse: rays 3 or 4 mm. long: the 1 or 2 awns 2 mm. long, usually with dilated bases: akenes 3½ or 4 mm. long. — Southeastern Arizona and adjacent Mexico. ARIZONA, Bisbee (F. E. Lloyd); SONORA, Cocuto (Hartman, no. 70); CHIHUAHUA, Janos (Schott).

+ + Involucre about 8-bracteate.

++ Bracts broad-linear, flat at least above the middle, very obtuse.

= Pappus of both ray- and disk-akenes aristiform.

P. Pringlei. Low, 5 or 6 cm. high, divergently much-branched, with strongly angulate glabrous branches and peduncles: leaves revolute, slender, mucronate, equalling or longer than the internodes, 1 to 2 cm. long, barely 1 mm. wide, with 2 pairs of basal setæ: peduncles 1½ to 2½ cm. long, usually 1–2-bracteate: involucre 5 or 6 mm. high, about 25-flowered; the bracts plane above, strongly keeled below, bearing a large apical gland, and 1 or 2 smaller ones below: rays 5 mm. long: pappus 2 or 3 very slender awns 3 to 5 mm. long, slightly dilated below: akenes equalling or slightly exceeding the awns. — DURANGO, Jimulco (Pringle, no. 125).

= = Ray-pappus aristiform, disk-pappus squamellose.

P. Rusbyi, Greene. "Mint-scented," low, hardly 1 dm. high, simple or divergently but sparingly branched, the angulate stems and peduncles glabrous: leaves flat or a little revolute, spatulate-linear, with blunt or rounded tips (or a few mucronulate), 2 to 3½ cm. long, 1 to 3 mm. wide, with 2 or 3 pairs of setæ: peduncles 3 to 6 cm. long, 2–5-bracteate: involucre 4 to 6 mm. high, 30–40-flowered; the flattish bracts slightly keeled below, each bearing a large apical gland: rays 6 mm. long: ray-pappus 2 or 3 very slender awns 2½ or 3 mm. long, scarcely dilated below; disk-pappus a crown of many setaceous-tipped squamellæ, free or united at the base: akenes 4 mm. long, sparingly setose or glabrate. — Greene in Gray, Syn. Fl. i. pt. 2, 361. — ARIZONA, Beaver Creek (Rusby, no. 317).

++ ++ Bracts narrow-linear, involute, acutish. (Forms of *P. papposa* may be looked for here.)

= Pappus aristiform.

P. Rosei. Very diffusely branching from the base; the purplish terete stems smooth: leaves strongly revolute, becoming subterete, mucronate, equalling or exceeding the internodes, 2 to 4 cm. long, ½ to 1 mm. wide, with 2 pairs of basal setæ: peduncles many, terete, 2 to 4 cm. long, 4–6-bracteate: involucre 3 or 4 mm. high, about 20-flowered, the acutish bracts strongly keeled and bearing conspicuous elongated black glands: rays narrow, 3 mm. long, becoming rosy-tinged: pappus 2 or 3 slender awns 2 mm. long, and often a minute squamellose cup: akenes barely 3 mm. long, spreading-hirsute. — *P. punctata*, Rose, Contrib. U. S. Nat. Herb. i. 105, not Jacq. — SONORA, common on stony ridges, Alamos (Palmer, September, 1890, no. 730).

§ 3. PECTOTHRIX, Gray. Pappus of many (10 or more) capillary bristles, at least in the disk-flowers (or in *P. papposa* rarely reduced to a mere crown), a few of them sometimes enlarged but hardly paleaceous. — Pl. Fendl. 62, Pl. Wright. i. 83 & Proc. Am. Acad. xix. 47. *Cryptopetalon*, Cass. Bull. Soc. Philom. janvier, 1817, & Dict. Sci. Nat. xii. 123. *Lorentea*, Less. Linnæa, v. 135, in part; DC. Prodr. v. 101, in part; Gray, Pl. Wright. i. 83, in part [as section].

* Erect or suberect plants with ascending or spreading branches and ascending rigid leaves.

+ Annual, branching mostly above the middle.

P. elongata, HBK. Stems rather stiff, purplish, simple below, with ascending or spreading branches; stems subterete, smooth, the branches slightly tetragonous: leaves linear, submucronate, smooth or scabridulous above, 1½ to 4½ cm. long, 1½ to 3 mm. wide, with 4 or 6 irregular rows of conspicuous glands beneath, and 4 to 10 pairs of basal setæ: heads scattered or subcorymbose toward the tips of the upper branches; the slender peduncles ½ to 2 cm. long, generally with 2 approximate submedian bracts and often a third one above: involucre 5-bracteate, 5 mm. high, 10–12-flowered; the purplish bracts linear, acuminate, glabrous: rays small, yellowish: pappus 10–25 (sometimes reduced even to 3 or 4) upwardly scabrous unequal rufescent bristles slightly or not at all dilated below, the longest about 4 mm. long: akenes compressed, 2 to 2½ mm. long, setulose with rufescent hairs. — Nov. Gen. et Spec. iv. 262, t. 392; DC. Prodr. v. 99; Baker in Mart. Fl. Bras. vi. pt. 3, 288; Hieronymus in Engler, Bot. Jahrb. xix. 60. *P. stricta*, Willd. in Less. Linnæa, vi. 710, in syn. *Lorentea polycephala*, Gardn. in Hook. Lond. Journ. Bot. v. 240 *fide* Baker l. c. — A common South American species extending north to Guatemala. GUATEMALA, Chupadero, Depart. Santa Rosa (Heyde & Lux in Exsic. J. D. Smith, no. 3806); PANAMA (Seemann). Both these specimens have the pappus-bristles greatly reduced in number, but otherwise they seem identical with the true South American plant as figured with the original description. A specimen from Nicaragua (Chas. Wright) which Dr. Gray thought might be a form of *P. Berlandieri*, is too old for determination, but it may belong here.

Var. Schottii. Much more slender with very slender diffuse branches and small leaves: heads scattered and solitary in the axils, on capillary 3–4-bracteate peduncles 2 or 3 cm. long: involucre pale, 4 mm. high: pappus hardly equalling the akene. — YUCATAN, Maxcanu (Schott, 1865, no. 666). Type in Herbarium of Field Columbian Museum.

+ + Perennial, stems suberect branching from near the base.

P. diffusa, Hook. & Arn. A decimeter or so high, with a few suberect branches rising from the slightly suffruticose base, these branches simple or with short densely leafy branchlets above; stems angulate or subterete, smooth or puberulent, densely clothed with ascending leaves: leaves linear, thick, submucronate, with prominent midribs, smooth or scabrous on both surfaces, the larger 3 or 4 cm. long, 2½ or 3 mm. wide, with or without 2 or 4 irregular rows of dots beneath, and with 5 to 10 pairs of setæ below the middle (setæ reduced or sometimes wanting on the upper leaves): peduncles capillary, from the upper axils, 1 to 4 cm. long, with 2 to 6 scattered subulate-ovate bracts: involucre 4 to 6 mm. high, of 5 oblong acutish or obtuse bracts, 10–12-flowered: rays linear-oblong, yellow, 6 or 7 mm. long: pappus of 10 to 20 (rarely only 4 or 5) very unequal setiform bristles, the longer a little or not at all dilated below, and often with an exterior series of minute setæ at the base: akenes short-setose or glabrate. — Bot. Beech. 296; Gray, Pl. Fendl. 62, excl. syn. & Proc. Am. Acad. xix. 47, in part; Hemsley, Biol. Centr.-Am. Bot. ii. 225, in part; Rose, Contrib. U. S. Nat. Herb. i. 338. *P. Taliscana,* Benth. Pl. Hartw. 121, not Hook. & Arn. *fide* Hemsl. l. c. — Southwestern Mexico. Jalisco (Beechy in Hook. & Arn. l. c.), Rio Blanco (Palmer, 1886, no. 4), dry rocky hills near Guadalajara (Pringle, no. 1814); Colima, common on river banks at Colima (Palmer, 1891, no. 1155). Gregg's no. 967 (no locality given) is doubtless the same thing. The pappus of this as well as the last species is very variable in the number of bristles, which are sometimes reduced to 3 or 4, thus forming a transition to § *Pectidopsis.* The Nicaragua and Panama specimens referred here by Hemsley are more likely *P. elongata.*

* * More diffusely branched from near the base: leaves less rigid and more spreading: heads small or middle-sized.

+— Annuals, the pappus mostly barbellate-setose (in *P. papposa* sometimes reduced to a mere crown).

P. papposa, Harv. & Gray. Stems smooth, much-branched, the divergent branches 3 dm. or less in length: leaves fleshy, narrow-linear, 1 to 6 cm. long, 1 or 2 mm. wide, rarely with a few sharp lobes, bearing 2 rows of prominent marginal glands and 2 to 5 pairs of basal setæ: heads subfastigiate, or subcorymbose on slender 1–3-bracteate peduncles 2 or 3 cm. long, the bracts often glandular: involucre 4½ to 7 mm. high, about 20-flowered; the 7 to 9 linear strongly involute obtusish bracts more or less punctate: rays yellow, 4 to 8 mm. long: disk-pappus 12 to 20 unequal generally barbellate-setose bristles, 4 mm. or less in length, or sometimes reduced to a mere auriculate crown; ray-pappus a squamellose or auriculate crown, rarely with 1 or 2 slender awns, or even obsolete: akenes 3 or 4 mm. long, hispidulous or strigose with minute uncinate or capitate bristles. — Harv. & Gray in Gray, Pl. Fendl. 62; Gray, Pl. Wright. ii. 69, in Torr. Bot. Mex. Bound. 73 & Syn. Fl. i. pt. 2, 361; Hemsley, Biol. Centr.-Am. Bot. ii. 226. *P. tenella,* Rothr. in Wheeler, Rep. vi. 171, not DC. *P. Palmeri,* Wats. Proc. Am. Acad. xxiv. 58, as to Palmer's no. 655. — Sandy or gravelly soil, Southwestern United States to Sonora and Lower California. New Mexico, Doña Ana (C. Wright, no. 1126), Camp Bowie (Rothrock, no. 446), Deming (G. M. Kellogg); Arizona (S. Hayes, no. 342), Fort Whipple (Coues & Palmer, no. 522^{a}), Yuma (Pringle, no. 322), Maricopa (Pringle, no. 123), Tucson (Toumey, no. 675); California (Coulter, no. 331), San Diego Co. (Palmer, 1875, no. 200), El Rio (Lemmon, no. 78); Sonora, Valley of the Cocospera (Schott), Guaymas (Palmer, 1887, no. 655); Lower California, San Gregorio (Brandegee). Said to be lemon-scented.

P. Palmeri, Watson. A little stouter than the last: leaves mostly broader and thinner, about 4 cm. long, 2 to 4 mm. wide, with 1 or 2 short basal setæ: peduncles thicker, longer, scattered, 3 to 8 cm. long, 3–8-bracteate: involucre 5 to 6 mm. high, 35–50-flowered; the bracts plane, keeled below the middle: disk-pappus as in the last or merely scabrous; ray-pappus of 2 or 3 slender aristæ 3 mm. long, somewhat dilated at bases: akenes 4 mm. long, strigose with clavellate, not uncinate or capitate, hairs. — Proc. Am. Acad. xxiv. 58; Rose, Contrib. U. S. Nat. Herb. i. 338. — On foothills and in rich soil along streams, Sonora and Lower California. Sonora, Guaymas (Palmer, 1887, nos. 652, 653), Agiabampo (Palmer, 1890, no. 765); Lower California, Purissima, 1889 (Brandegee), La Paz (Palmer, 1890, no. 115). The Lower Californian plants are smaller and with fewer-flowered heads than the original Sonora specimens, but otherwise they are the same.

+ + Perennials or rarely annuals, the pappus merely scabrous.

P. stenophylla, Gray. Very diffusely branching from a suffruticose base, the branches purplish, slender, glabrous, 2 or 3 dm. long: leaves narrowly linear, mucronate, 3 or 4 cm. long, 2 mm. wide, or generally strongly revolute and scarcely 1 mm. wide, bearing two rows of marginal glands and 2 or 3 pairs of long slender basal setæ: heads scattered toward the tips of the branches; the filiform 4–6-bracteate peduncles becoming 5 or 6 cm. long: involucre 5 mm. high, 15–18-flowered; the 8 narrowly oblong bluntish bracts plane above, slightly keeled below the middle: rays yellow, narrow: disk-pappus of 20 to 40 unequal upwardly scabrous capillary bristles 2 mm. or less in length; ray-pappus 2 slender smooth or minutely scabridulous awns 1½ mm. long, slightly dilated below: akenes 2½ to 3 mm. long, sparingly pubescent with short clavellate hairs. — Proc. Am. Acad. xxi. 393. — Hillsides and dry soil, Northern Mexico. Chihuahua, Batopilas (Palmer, 1885, no. 81); Sonora, Arroyo Hondo (Hartman, no. 216, in part), Badehuachi (F. E. Lloyd, no. 402). Said to be aromatic.

P. Hænkeana, Schz. Bip. Perennial from a suffruticose base, or annual, the stems puberulous or pubescent, ascending or somewhat depressed, the longest 2 dm. in length: leaves pale green, linear or spatulate-linear, mucronate, 1 to 2½ cm. long, 1½ to 4 mm. wide, smooth or slightly pubescent on both surfaces, slightly revolute, entire, or rarely obscurely pinnatifid at the base of the 2 to 5 scattered setæ, faintly punctate-dotted in 2 or 4 lines: peduncles axillary or terminal. capillary, 1 to 3 cm. long, 2–5-bracteate: involucre 5 mm. high, 25–30-flowered, the 5 oblong obtuse plane bracts smooth, ciliate at the tips, faintly marked with elongate glandular dots: rays ovate-oblong, 4 mm. long: pappus clear-white, in the disk of 5 or 6 elongate scabrous setæ $3\frac{1}{2}$ to 5 mm. long, and many unequal shorter capillary ones; in the ray generally fewer: akenes 3 or 4 mm. long, setose or glabrate. — Sch. Bip. in Seem. Bot. Voy. Herald, 309; Gray, Proc. Am. Acad. xix. 47. *P. capillipes*, Hemsley, Biol. Centr.-Am. Bot. ii. 225. *Lorentea Hænkeana*, and varieties, DC. Prodr. v. 102. *L. capillipes*, Benth. in Œrsted, Vidensk. Meddel. 1852, 70. — Mexico (Hænke *fide* DC.); OAXACA, San Antonio (Pringle, no. 5760), Cuicatlan (Nelson, no. 1598, L. C. Smith, no. 422). NICARAGUA, Segovia (Œrsted *fide* Benth. l. c.). Without authentic specimens, it is impossible from the description alone to distinguish Bentham's plant from De Candolle's. In the Oaxaca material, which is apparently all the same species, the suffruticose character is found only in Mr. Pringle's plant.

* * * Perennials, the stems subsimple or sparingly branched, mostly decumbent or procumbent from woody or suffruticose bases, rarely ascending with subsimple branches above: heads many (30–90)-flowered.

P. longipes, Gray. The glabrous slender densely leafy stems forming tufts or depressed mats, including the long scape-like peduncles $1\frac{1}{2}$ or 2 dm. high: leaves thickish, linear, mucronate, 2 to 4 cm. long, $1\frac{1}{2}$ to 3 mm. wide, bearing conspicuous marginal glands and 2 or 3 pairs of basal setæ: peduncles 6 to 14 cm. long, naked or few-bracteate: involucre broadly campanulate, 6 or 8 mm. high, 50–90-flowered; the 12 or 15 plane linear acutish bracts each bearing a large apical gland and rarely one or two toward the base: rays bright yellow, narrowly oblong, 1 cm. or less in length; disk-pappus 20 to 40 very unequal subbiseriate capillary upwardly scabrous bristles, the longest 4 to 6 mm. long, the shorter outer ones generally more slender; ray-pappus 2 slender setulose awns 3 to 5 mm. long, and rarely a few reduced bristles at the base: akenes 4 or 5 mm. long, more or less pubescent with short recurved unequally bidentate hairs. — Pl. Wright. ii. 69, in Torr. Bot. Mex. Bound. 73, in part, & Syn. Fl. i. pt. 2, 361; Hemsley, Biol. Centr.-Am. Bot. ii. 226, in part; Rose, Contrib. U. S. Nat. Herb. i. 122. — Mesas and mountain sides, Southwestern Texas (Coulter, Contrib. U. S. Nat. Herb. ii. 238) to S. Arizona and adjacent Mexico. ARIZONA, between the San Pedro and Santa Cruz (C. Wright, no. 1127), Apache Pass (Lemmon), Foothills of Santa Rita Mts. (Pringle), Fort Huachuca (Palmer, 1890, no. 425); SONORA, Santa Cruz and Babocomori (Thurber, no. 996), Sonoyta valley (Rothrock, no. 635); CHIHUAHUA, San Diego (Hartman, no. 609).

P. canescens, HBK. Stems glabrous or puberulous or more or less canescent-hirtellous, from a few centimeters to 3 dm. in length: leaves rather rigid, linear or linear-oblong, acute, mucronate, 1 to 2½ cm. long, 1 to 4 mm. wide, minutely punctate, entire or pinnatifid-dentate, with 2 to 10 pairs of setæ: peduncles terminal, slender, 1 dm. or less in length, 4–10-bracteate: involucre 6 to 8 mm. high, about 40-flowered; the 5 to 9 lanceolate to spatulate-obovate smooth plane bracts blunt or rounded at the ciliate tips, usually glandless and prominently keeled toward the bases: rays lance-oblong, yellow, 6 or 8 mm. long: disk-pappus 20 to 30 unequal rufescent mostly capillary setæ, a few of the longest somewhat stouter, 6 or 8 mm. long; ray-pappus as in the disk or of fewer setæ (*latisquama*), or reduced to a few subulate squamellæ (*canescens*), or auriculiform (*auricularis*), or entirely wanting (*satureioides*): akenes 6 mm. long, spreading-hirsute. — Nov. Gen. & Spec. iv. 263, t. 393, Gray, Proc. Am. Acad. xix. 47. *P. longipes*, Hemsley, Biol. Centr.-Am. Bot. ii. 226 (as to Berlandier plant), not Gray. *P. multiflosculosa*, Hemsl. l. c. not Schz. Bip. *Inula Saturejaoides*, Mill. Dict. ed. 8; *I. saturejoides*, Willd. Sp. Pl. iii. 2104; *I. Satureiæ*, Spreng. Syst. iii. 520. *Aster Saturejæ*, Banks in Reliq. Houst. 8, t. 19. *Lorentea saturejoïdes*, Less. Linnæa, v. 135 & vi. 718; DC. Prodr. v. 102 (*satureioides*). *L. canescens*, Less. l. c. vi. 718; DC. l. c. *L. auricularis* & var. *Acapulcensis*, DC. l. c. *Stammarium hyssopifolium*, Willd. in Less. Linnæa. v. 135, in syn. *Lorentea multiflosculosa*, DC. (Prodr. v. 102) is probably referable here. It is not, according to Bentham and Hooker f., or Klatt, the *Pectis multiflosculosa*, Schz. Bip. (see note under *P. arenaria*); and from De Candolle's description and note it seems very near if not quite *P. canescens*. A drawing, kindly furnished by Mr. Thiselton-Dyer, of Œrsted's Guanacaste plant (see Benth. in Œrsted, Vidensk. Medd. 1852, 70) shows that plant to be a form of *P. canescens* (*latisquama*). — Dry ground, mostly in the mountains, Central Mexico to Costa Rica. SAN LUIS POTOSI, near Sta. Maria (Schaffner, no. 370), between San Luis Potosi and Tampico (Palmer, 1878–79, no. 1097); NUEVO LEON (Berlandier, no. 3159); VERA CRUZ, near Vera Cruz (Houston *fide* Banks, l. c.), Wartenberg, near Tantoyuca (Ervendberg, no. 63); PUEBLA, Tehuacan (Galeotti *fide* Hemsl.); MEXICO, Valley of Mexico (Schaffner, no. 85), near Santa Fé (Schiede

& Deppe *fide* Lessing); JALISCO, Tequila (Palmer, 1886, no. 418); OAXACA (Galeotti *fide* Hemsl.); GUERRERO, Chilpancingo (Humboldt & Bonpland *fide* HBK.), Acapulco (Hænke *fide* DC.); NICARAGUA (C. Wright); COSTA RICA, Guanacaste (Œrsted).

Var. villosior, Coult. Low with thick woody caudex: stems and leaves villous or even lanate; the involucral bracts puberulous or villous. — Bot. Gaz. xx. 52. — OAXACA, between Tatolapa and San Carlos (Nelson, no. 2550); GUATEMALA, Santa Rosa (Heyde & Lux in Exsic. J. D. Smith, nos. 3401, 3413).

P. Liebmannii, Schz. Bip. Suffruticose at base, the elongated slender procumbent branches 2 or 3 dm. long, the whole plant including leaves and involucre canescent-tomentose or even lanate on the young parts: the thick obovate-oblong revolute leaves cuspidate-mucronate, about 2 cm. long, 1 cm. or less wide, punctate beneath, with many small black dots, and 2 to 4 (according to Klatt 6 or 8) long basal setæ: peduncles solitary, terminal or axillary, 6 mm. or less long, 2–3-bracteate: involucre 6 or 7 mm. high, about 30-flowered; the 6 or 8 linear-oblong rosy-tipped bracts plane or somewhat involute, scarious on the margins, canescent on the back, and slightly thickened below: rays yellow, ovate-lanceolate, 3 or 4 mm. long: disk-pappus 20 or 30 unequal sordid upwardly scabrous setæ, the longest 4 or 5 mm. long; ray-pappus wanting: akenes narrowly fusiform, 3 or 4 mm. long, minutely pubescent or glabrate. — Schz. Bip. in Hemsley, Biol. Centr.-Am. Bot. ii. 226 & in Klatt, Leopoldina, xx. 92 (reprint 5). Southwestern Mexico. "Lag. Lapotengo" (Liebmann, no. 471 *fide* Klatt l. c.); JALISCO, San Augustin (Liebmann, no. 467).

* * * * Aquatic subsimple plant with naked leaves and subsessile heads.

P. aquatica, Watson. Stems smooth, elongated, simple, or sparingly branched; leaves few, mostly above, thick, linear, entire, blunt, 2 or 3 cm. long, rarely with a few faint marginal glands: heads solitary in the axils, becoming recurved with age: involucre about 1 cm. high, of 5 imbricated flat obtuse purple-tipped blunt bracts, about 12-flowered, the flowers mostly included: rays none: pappus of 10 or 12 unequal serrulate bristles, the longest 2 mm. long and somewhat thickened, all ascending or converging at the tips: akenes compressed-angulate, very slender, 8 mm. long, with a long-attenuate base, appressed-setose with rufescent hairs. — Proc. Am. Acad. xxiii. 279. CHIHUAHUA, pine plains, base of Sierra Madre (Pringle, no. 1296). A unique species, the stems floating in ponds.

§ 4. HETEROPECTIS, Gray. Low diffuse puberulent plants with setiferous leaves: rays bright yellow: pappus of corneous subulate divergent retrorsely barbed awns (or reduced in the disk to a mere crown of rigid squamellæ). — Pl. Wright. i. 83. *Pectis* § *Pectidium*, Gray, Proc. Am. Acad. xix. 48, in part.

* Leaves thick, serrulate, the teeth and the tip continued into long setæ.

P. multiseta, Benth. Annual, stouter than the related species, 3 dm. or less high: leaves with slightly revolute margins, lanceolate, 1 to 2½ cm. long, the lower surfaces covered with scattered large glands and smaller punctate dots: peduncles becoming 3 cm. long: involucre 4½ mm. high, 20–25-flowered, of 5 obovate-cuneate punctate and ciliate bracts: rays 6 mm. long: awns unequal in length (2 mm. or less), in the ray-flowers 3, in the disk-flowers 1 or 2, or the pappus reduced to a mere crown of more or less connate squamellæ: akenes 3 or 4 mm. long, pubescent with long somewhat capitate hairs. — Bot. Sulph. 20. — LOWER CALIFORNIA, Cape St. Lucas (Hinds *fide* Bentham, l. c. Xantus).

* * Leaves thinner, setiferous only below the middle.

P. Coulteri, Harv. & Gray. Annual or perennial (?), slender, very diffuse and branched, 2 dm. or less in height: leaves narrowly linear, usually with revolute margins, 3 cm. or less in length, generally with 2 rows of glands on the lower surfaces; setæ restricted to the subpinnatifid basal half of the leaf: peduncles varying in length from 3 or 4 mm. to 3½ cm.; involucre cylindraceous, 12–20-flowered, 5 to 7½ mm. high, of 5 (or by exception 6) linear-oblong often glandular-dotted ciliate bracts: rays 5 to 7 mm. long: awns somewhat unequal in length, in the rays 3 to 6, in the disk 2 to 5 (generally 3 or 4), about 1½ mm. long: akenes slender, 4 or 5 mm. long, strigose-pubescent with capitate hairs. — Harv. & Gray in Gray, Pl. Fendl. 62; Watson, Proc. Am. Acad. xxiv. 58. — On sandy plains, Arizona to the Sonora coast, "California," i. e. probably on the Gila River[1] (Coulter, no. 330); ARIZONA (Palmer), Sonora Alta (Coulter, no. 441 *fide* Hemsley); SONORA, Guaymas (Palmer, 1887, nos. 143, 654, 1890, no. 759). Dr. Palmer's Sonora specimens are much more vigorous throughout than the earlier-collected specimens from the Arizona desert region, but, except in size, the plants seem to be the same.

P. ambigua. Annual, similar in habit to *P. Coulteri*, but smaller, 1 dm. or less in height: leaves thin, entire, linear or spatulate-linear, flat, barely 1 cm. long, with the glandular dots irregularly scattered over the lower surfaces, and with only 1 or 2 pairs of basal setæ: peduncles 2 to 7 mm. long: involucre oblong, 10–12-flowered, 3 or 4 mm. high, of 5 linear-oblong more strongly costate glandular-dotted bracts: rays 3 or 4 mm. long: pappus of the ray-akenes three awns, the longest 1 mm. long, of the disk-akenes a minute squamellose crown: akenes 3 mm. long, sparingly pubescent with capitate hairs. — *P. multiseta*, Vasey & Rose (misprinted *multisecta*), Contrib. U. S. Nat. Herb. i. 72, not Benth. — LOWER CALIFORNIA, San Gregorio (Brandegee, 1889), common on sandy mesas, La Paz (Palmer, 1890, no. 23).

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[1] Coville, Bot. Gaz. xx. 528.

§ 5. PECTIDIUM, Gray. Erect glabrous plants with the leaves entire, naked or sparingly setiferous at base: rays white or whitish becoming purple: pappus of rigid smooth awns with or without a few aristiform paleæ and squamellæ, or reduced to a crown of corneous squamellæ, or even obsolete. — Pl. Wright. i. 83, & Proc. Am. Acad. xix. 48, in part. *Pectis*, Cass. in Dict. Sci. Nat. xxxviii. 202. *Pectidium*, Less. Linnæa, vi. 706.

* Slender annuals with thin leaves sparingly setiferous at base (very rarely naked): rays 1 or 2 mm. long: pappus consisting only of 2 or 3 corneous smooth (rarely a little denticulate) subulate divergent awns. — *Pectis*, Cass. l. c. *Pectidium*, Less. l. c.

P. linifolia, L. Rather tall and slender, 3 to 9 dm. high, paniculately branched: leaves plane or slightly revolute, linear or linear-lanceolate, the largest 5 or 6 cm. long, 5 mm. wide, dark green above, glaucous beneath and covered with many small round glands, with larger elongated ones along the margin: peduncles becoming 2 or 3 cm. long, with 1 or 2 minute bracts above the middle: involucre glabrous or minutely puberulent, 5 or 6 mm. high, 6–9-flowered, of 4 or 5 narrow linear blunt bracts, marked longitudinally with black glands and soon becoming involute: awns 2 or 2½ mm. long: akenes minutely puberulent or glabrate, 4 mm. long. — Syst. Nat. ed. 10, 1221 (Sloane, Hist. Jam. t. 149, f. 3) & Amœn. Acad. v. 407 (*Tagetes* ? 2, Browne, Jam. 319); Gærtn. Fruct. t. 171; Lam. Ill. t. 684; Cass. l. c. *P. punctata*, Jacq. Enum. Pl. Carib. 28 & Stirp. Amer. 216, t. 128; L. Spec. ed. 2, 1250; Swartz, Obs. 308; Cass. in Dict. Sci. Nat. l. c.; Gray, Syn. Fl. i. pt. ii. 362. *Pectidium punctatum*, Less. Linnæa, vi. 707; DC. Prodr. v. 98. — YUCATAN (Gaumer, no. 887); LOWER CALIFORNIA, Cape St. Lucas (Xantus, no. 45). Common in the West Indies and reported from Venezuela and Galapagos.

Var. marginalis. More slender than the type, ascending, not so tall (the tallest about 4 dm. high): leaves pale green with remote orange-red oblong marginal glands (very rarely a few glands scattered on the lower side of the leaf): heads a little longer than in the type: awns 2 mm. long: akenes 6 or 7 mm. long. — *P. punctata*, Wats. Proc. Am. Acad. xxiv. 58, not Jacq. — In shaded ravines and on mountain bluffs, Southern Arizona to the Sonora coast. ARIZONA (Palmer, 1867, no. 129), Tuscan (Smart, no. 382), Santa Catalina (Lemmon, no. 3031), Malpais Mts. (Pringle); SONORA, Guaymas (Palmer, 1887, no. 224).

* * Rigid glaucous perennial with ligneous root: leaves entirely without setæ: rays 6 to 9 mm. long: pappus various, erect, not divergent, the aristiform pales, when present, generally minutely serrulate.

P. imberbis, Gray. Stems sulcate, 3 to 9 dm. high, paniculately branched, sparingly leafy and junciform: leaves thick, linear, with revolute margins, the longest 6 or 7 cm. long, channelled above, and with the midrib very prominent beneath; lower surfaces with two rows of scattered elongated dark glands: peduncles about 2 cm. long, with a few linear-subulate bracts, especially toward the tips: involucre cylindrical, 7 or 8 mm. high, 10–12-flowered. of 5 or 6 linear blunt soon involute bracts marked with linear dark glands: disk-corollas with five longitudinal purplish stripes along the tube and with a conspicuous dark gland at the tip of each lobe; rays with or without one or two small glandular dots: akenes puberulent, 5 or 6 mm. long. — Pl. Wright. ii. 70 & in Torr. Bot. Mex. Bound. 73; Rothrock in Wheeler Rep. vi. 172. — Southern Arizona and adjacent Mexico. ARIZONA, near Fort Huachuca (Lemmon, no. 2783); SONORA, Sonoyta Valley (Wright, no. 1399, Rothrock, no. 636). CHIHUAHUA, Janos (Schott). Said to have a strong terebinthine odor.

II. — SOME RARE AND UNDESCRIBED PLANTS COLLECTED BY DR. EDWARD PALMER, AT ACAPULCO, MEXICO.

SCLERIA LITHOSPERMA, Willd., var. FILIFORMIS, Britton, Ann. N. Y. Acad. Sc. iii. 231. Forming tussocks among underbrush on hills above Acapulco, November, 1894 (no. 76). Common in South Florida and the West Indies, the type occurring in Southern Asia and Australia.

Ruprechtia fusca. A tree about 4½ m. high, the trunk 2 dm. in diameter: bark of the slender branches pale brown, puberulent or glabrate, somewhat sulcate and verrucose: ochreæ cylindric, puberulent, 7 mm. long, soon deciduous: leaves obovate, 5 to 9 cm. long, 2½ to 4½ cm. broad, coriaceous, on thickish petioles 3 to 6 mm. long, below subcuneate, above blunt or rounded, or short-acuminate to a blunt tip; the margins undulate and revolute; upper surfaces minutely puberulent, lower densely fuscous-pubescent, except on the glabrate and slightly verrucose midribs; the veins above strongly impressed, beneath, with the strongly reticulating veinlets, prominent, meeting the midrib at an angle of 45 degrees: racemes, with the bracts, short fuscous-pubescent, lateral in sessile fascicles 4 or 5 cm. long, in fruit densely covering the leafless branches: fruiting pedicels slender, villous, 4 mm. long, articulated above the middle: the outer fruiting calyx 3 cm. long, dividing 2 mm. above the middle into three spatulate-linear reticulated wings, appressed-pubescent below, the wings becoming glabrate toward the tips; inner calyx-lobes linear-subulate, glabrous, about 4 mm. high, closely appressed to the deeply sulcate faces of the akene: akene narrowly ovate, acuminate, 7 mm. long, appressed-villous; below terete, with broad rounded angles and deeply sulcate faces; above sharply angulate; persistent styles 1 mm. long, equalling the linear stigmas. — Collected on rocky hillsides, January, 1895 (no. 511). A species in some ways suggesting *R. Cumingii*, Meissn., but apparently well distinguished from that species by its smaller obovate pubescent leaves, and its fascicled longer racemes.

ACALYPHA INDICA, L. Spec. 1003. Common about shady walls and buildings and along stony arroyos, November, 1894 (no. 46). Perhaps introduced; native in Southern Asia and Tropical Africa.

Acalypha Acapulcensis. A very slender shrub; the dark brown bark finely appressed-pubescent: stipules subulate, 1 mm. long, tipped by a pair of minute white hairs: leaves 2 to 4 cm. long, ovate or ovate-lanceolate, acuminate at the tip, rounded or subcuneate at the base, pinnately veined, minutely pruinose above, and appressed-pubescent on the veins beneath, rather coarsely crenate-dentate; on slender petioles $\frac{1}{3}$ to $\frac{1}{5}$ as long: spikes monœcious, axillary, pubescent; the staminate spikes very slender and short-peduncled (sometimes with one or two pistillate flowers at the base), 2 cm. or less long, 1 mm. thick, the minute flowers hispid; pistillate spikes sessile, becoming 3 cm. long, with 6 to 9 scattered bracts: bracts 2-flowered, reniform, 4 mm. long, 5 or 6 mm. broad, with 16 crenate teeth: the three red styles each deeply cut into 4 or 5 segments: capsule hispid; seed ovate, minutely puncticulate, 1 mm. long. — In shady river-bottoms and depressions in the mountains, November, 1894 (no. 190).

Lucuma Palmeri. A shrub, $1\frac{1}{2}$ to 3 m. high; the reddish brown bark of the young branches appressed-pubescent with ferruginous hairs, becoming glabrate: leaves dark green, ferruginous-pubescent when young, soon becoming glabrate and shining above, scarcely paler beneath, oblanceolate or narrowly obovate, subcuneate at the base, obtuse, rounded or even retuse at the apex, 6 to 12 cm. long, 2½ to 5½ cm. broad, the veins prominent beneath, the veinlets inconspicuously reticulated; petioles appressed-pubescent, 9 to 15 mm. long: flowers solitary or in clusters of 2 or 3, above the axils; peduncles appressed-pubescent, 1 or 2 cm. long: sepals 5, suborbicular, obtuse, imbricated, ferruginous-pubescent, 5½ mm. long: corolla twice as long as the calyx, cylindric-campanulate, deeply cleft into 5 (or 7) oblong obtuse lobes, puberulent, and appressed-ferruginous outside: stamens and staminodia equally inserted at the top of the corolla-tube, the stamens on short filaments equalling the anthers; the staminodia linear-subulate, about equalling the stamens: ovary pubescent, 5-celled: fruit short-oblong or globular, 3 cm. long, sinuately 5-lobed (by abortion 4- or even 1-locular), yellow when ripe; seed 2½ cm. long, ellipsoidal, laterally compressed, the testa straw-colored and shining, the ventral hilum elongated-oblong. — Acapulco, January, 1895 (no. 386). Called "Huicon," and the yellow fruit eaten. The seed places this plant in De Candolle's section *Guapeba*, but the 5-parted calyx and corolla throw it out of that section and place it near *L. Rivicoa*, Gærtn., or *L. nervosa*, DC., in neither of which, however, is the seed laterally compressed. Dr. Palmer's no. 1346 from Manzanillo, described by Dr. Rose without a name (Contrib. Nat. Herb. i. 339), may be a form of this species with much longer leaves and petioles.

MABA ALBENS, Hiern, Trans. Camb. Phil. Soc. xii. 126. A shrub 2 or 3 m. high: stems few, about 2½ cm. in diameter, covered with smooth pale bark: branches covered with rough reddish-brown bark: leaves subcoriaceous, alternate, broadly oblanceolate, 5 to 9 cm. long, 2 to 3 cm. broad, blunt or rounded at the apex, tapering below to a short petiole a line or so long, minutely strigillose-pubescent beneath, above puberulous, becoming smooth and shining; margins entire, revolute; midribs slightly depressed above, prominent beneath: fruit solitary on thick peduncles 2 mm. long, subglobose, 2 or 3 cm. in diameter, minutely appressed-pubescent, especially about the persistent base of the style; skin thin, greenish yellow; pulp edible: seeds 6, about 1½ cm. long, 8 mm. broad, and 6 mm. thick; albumen equable: fruiting calyx spreading, 1½ cm. across, 3-fid, densely appressed-pubescent within, sparingly so without; lobes broadly ovate, 6 to 9 mm. broad, the margins and tips recurved. — Acapulco. January, 1895 (no. 372). The yellow fruit eaten under the name "Coacollutillo." *Maba albens* has been known only from the flowering specimens, and Dr. Palmer's plant has therefore been placed there with some hesitation. The oblanceolate slightly pubescent old leaves, the pubescent calyx and fruit, and the pallid bark, agree very well with that species. *Maba albens*, however, is described as having dull green leaves when young and the midrib depressed beneath. In these fruiting specimens the leaves are glossy above and the midribs prominent beneath.

Evolvulus commelinifolius. An annual plant with sparingly branched lignescent stems 3 to 5 dm. high: stems and both sides of the leaves densely rufous-hispid and villous: lowest stem-leaves oblong, subsessile, blunt at the apex, acutish or rounded at the base, 4 or 5 cm. long, the upper gradually decreasing in size; floral-leaves becoming approximate, distichous, conduplicate, broadly deltoid-ovate, with deeply cordate bases, the lowest 4 cm. long, and 2½ cm. broad, the upper barely 1½ cm. long: flowers solitary, axillary, on very short peduncles: sepals lance-subulate, 6 mm. long, white with setose-hispid pubescence: corolla pale blue with white stripes, 13 mm. high: capsule obovate; seed olive-green with minute black dots. — Shady places in the mountains and river-bottoms, December, 1894 (no. 312).

Evolvulus ovatus. A prostrate much-branched plant: stems slender, 3 dm. long, densely silky-villous: leaves ovate, or oblong-ovate on the branchlets, acutish, subsessile, with cordate bases, silky-villous on both sides, 7 to 13 mm. long, 4 to 9 mm. wide, closely approximate, or even imbricated, toward the ends of the branches: flowers axillary, solitary, on very short peduncles: sepals densely villous, lanceolate, 4 to 7 mm. long: corolla blue, scarcely exceeding the calyx: capsule depressed-globose; seed smooth. — On a shady hillside, December, 1894 (no. 313). Near *E. holosericeus*, HBK., and *E. discolor*, Benth., but distinguished from them by the broader leaves with the upper surfaces pubescent.

Ipomœa (Pharbitis) ampullacea. A stout woody vine climbing high over trees and shrubs; the pale brown bark covered with appressed retrorse hairs: leaves broadly ovate or suborbicular, 7 to 15 cm. broad, deeply cordate at bases, short-acuminate, acute, or even obtuse, entire or shallowly 3-lobed, the lateral lobes blunt, strigose-pubescent, especially on the pale lower surface; the veins prominent beneath; petioles retrorse-strigose, ½ to 1 dm. long: peduncles stout, equalling or exceeding the leaves, puberulent toward the tips, branching into a loose cyme: pedicels 1 or 2 cm. long, thickened upward, generally bearing an oblong tuft of dense matted hairs: bracts strigose-pubescent, ovate-lanceolate, blunt, 1¾ cm. long: calyx strigose-pubescent; sepals coriaceous, unequal, the two outer much larger than the inner, 2½ to 4 cm. long, the body ovate, narrowed above to an elongated lanceolate or linear tip: corolla white, narrowly campanulate, 6 cm. long, strigose-pubescent in broad bands without: stamens hardly equalling the corolla, the filaments somewhat dilated below and pubescent with loose spreading hairs: ovary glabrous; the style slender, equalling the corolla; stigma 3-lobed: capsule depressed-ovoid, 1½ cm. high, 3-celled, 6-seeded; seed ovate, 6 or 7 mm. long, covered with short ferruginous pubescence. — A very showy plant, growing in low places among the mountains, January, 1895 (no. 483).

Ipomœa Palmeri, Watson, var. **platyphylla.** Leaves larger than in the type, the largest leaflets ovate-lanceolate, 1 dm. long, 3 cm. wide: peduncles bearing 1 to 3 dull-white nocturnal flowers: seeds oblong or oblong-ovate, 10 to 13 mm. long, more densely black-pubescent than in the species. — In high valleys among the mountains, January, 1895 (no. 415).

IPOMŒA FILIPES, Benth. ex Meissn. in Mart. Fl. Bras. vii. 274. A dainty little vine with minute yellow flowers. Among underbrush on high hills, and along arroyos, November, 1894 (no. 109).

Convolvulus secundiflorus. A delicate vine; stems twining, covered with scattered pilose hairs: leaves elongated, ovate-lanceolate, long-acuminate, deeply cordate, glabrous or granular-pubescent, with thin whitish and pilose margins, 2 to 4 cm. long, on pilose petioles 5 to 13 mm. in length: the 2–3-flowered racemes axillary, secund: the glandular peduncles 1½ to 3½ cm. long: bracts minute, subulate: pedicels glandular, 4 to 9 mm. long: calyx glandular and pilose without, 3 mm. long in flower, becoming elongated to 4 or 5 mm. in fruit; sepals elongate-lanceolate with subulate muriculate tips: corolla blue, glabrous, 9 mm. high, with the 5 angles acuminate: stamens unequal, the three longest 4½ mm. high, and equalling the style: stigma linear-oblong: seed pale brown, muriculate, barely 2 mm. long. — Among grass in the town, October, 1894 (no. 32).

Cordia (Dasycephalæ) perlonga. A shrub with very hard fine-grained wood, the dark brown bark dotted with orbicular or oblong white lenticels: young branches appressed-hispidulous and villous: leaves short-petioled, lanceolate, acuminate, coarsely and unequally serrate above the cuneate entire bases, 6 to 9 cm. long, 1½ to 2½ cm. broad; above dark green, appressed tuberculate-hispid; beneath white-villous, appressed-hispid on the veins: peduncles subterminal, becoming 1 or 2 dm. long, villous and sparingly hispidulous: heads at first globular, becoming short-oblong, in fruit 2 or 3 cm. long: calyx narrowly campanulate, white-villous below, appressed-hispid above; the hispidulous filiform teeth twisted and hooked at the tips, becoming 4 mm. in length: corolla white, early deciduous; the tube 13 to 15 mm. long, spreading above to a limb 2½ cm. broad, with shallow rounded lobes: stamens unequally inserted above the base of the minutely pubescent corolla-tube; anthers pubescent: stigmas filiform: fruiting calyx enclosing the ovate-oblong muriculate and minutely puberulent drupe. — Occurring rarely in the thickets upon hillsides, November, 1894 (no. 70).

Solanum lignescens. Erect, lignescent, 4 or 5 dm. high, sparingly branched, the older parts covered with a thin brownish cortex; branches, leaves, pedicels, and calyces viscid and covered with slightly fuscous stellate hairs: leaves mostly solitary, rarely geminate, ovate-oblong, entire, on thickish petioles 7 to 13 mm. long, acute at base, blunt or rounded at the apex, dull green and sparingly pubescent above, pale and densely pubescent beneath, especially on the midrib and the 7 to 11 lateral veins: umbels 3–6-flowered, subsessile a little below the leaves; the peduncles in fruit becoming 3 or 4 mm. long; pedicels reflexed, in anthesis 7 to 10 mm. long, in fruit becoming twice that length: calyx short-campanulate, 3 mm. long, with 5 oblong obtuse lobes: corolla white, minutely pubescent, 1½ cm. broad, with lance-ovate acute lobes: stamens oblong, about 4 mm. long: style slightly exserted: berries smooth, black, 12 mm. in diameter. — In fields, high up on the mountains, November, 1894 (no. 216). The fresh plant, according to Dr. Palmer, has the odor of tobacco.

Herpestis decumbens. Rather stout, 3 dm. or so high from a decumbent base; the hollow quadrangular stem much branched and delicately spotted with pale green and brown: leaves 4 or 5 cm. long, lanceolate, acuminate, with thickish margins, appressed-serrate above, cuneate below to half-clasping slightly decurrent bases, glabrous, irregularly pitted beneath: flowers solitary in the axils of the short upper leaves; pedicels about 2 mm. in length: calyx subtended by a pair of lanceolate bracts 4 mm. long; the three outer sepals ovate with rounded or subcordate bases, 7 to 9 mm. long, strongly nerved, the posterior larger than the others; inner sepals lanceolate, acuminate, glandular-ciliate on the margins and midrib, about 7 mm. in length: corolla bilabiate, scarcely exceeding the calyx, the upper lip 2-lobed; the tube sparingly pubescent below the four short stamens: ovary and capsule ovate-oblong, covered with pellucid dots; style thickish, dilated, 2-lobed at the apex: capsule 5 or 6 mm. high; seed minute, black, oblong, truncated, and strongly reticulated. — In wet bottoms, March, 1895 (no. 609). A rather stout plant resembling *H. sessiliflora*, Benth., but well distinguished by its coarser habit, larger leaves and pedicelled flowers, narrower capsule, thicker style, and larger seed.

Dyschoriste saltuensis. A slender suffrutescent plant: stems branching, subtetragonal, densely covered with short appressed hairs, ciliate at the nodes: leaves lanceolate, obtuse at the tips, tapering below into short petioles, the lower cauline 6 cm. long, 1½ cm. wide, the upper scarcely half as large, above covered with obscure linear markings, beneath strigillose-pubescent on the midrib: flowers axillary, solitary, or in glomerules of 2 to 5: peduncles 3 or 4 mm. long: bracts minute: calyx hirsute, 8 or 10 mm. long, divided half way to the base into 5 lance-subulate lobes: corolla light purple, pubescent without, 1½ cm. or less in length, the slender tube equalling the calyx and then spreading into a campanulate throat; lobes oblong, truncate, 4 mm. long: stamens didymous, hirsute; anther-bases mucronate: style hirsute: mature fruit not seen, but the young capsule oblanceolate, glabrous, hardly equalling the calyx. — Common among oaks in the higher mountains, January, 1895 (no. 506).

Ruellia albiflora. A small shrub: the pale brown bark covered with prominent ovate lenticels; upper branches, with the leaves and calyces, covered with pellucid or black granules: leaves mostly on the upper branches, oblong-lanceolate or narrowly ovate, tapering about equally to the bluntish tips and the short petioles (4 to 7 mm.); leaves of the primary branches 4 to 10 cm. long, 1½ to 4½ cm. wide, slightly appressed-pubescent on the midribs beneath, and with a few linear markings upon the epidermis above; those of the branchlets crowded and smaller, becoming even 1 cm. in length: flowers subsessile in the axils of the upper leaves, subtended by linear-spatulate bracts about equalling the calyx: calyx minutely puberulent, the tube 4 mm. long, the 5 lance-subulate lobes 6 or 8 mm. long: corolla white, puberulent without; the tube slender, 2 cm. long, spreading into a narrowly obconic throat 1 cm. high; limb with ovate lobes 8 mm. long: filaments sparingly pubescent; anthers linear, 2 mm. long: style hirsute; stigma 1 mm. long: pod narrowly obovate, 12 mm. long, 4 mm. wide, somewhat dorsally compressed, blunt above, subcuneate below, minutely white-puberulous; seeds 2 to 4, suborbicular, 3½ mm. long, appressed-pubescent, tipped by a minute white caudate appendage. — Collected at Acapulco, November, 1894 (no. 49); and formerly at Armeria (Palmer, 1891, no. 1274). This shrub is very showy in flower, and at Acapulco it grows abundantly in river bottoms and low rich spots among the mountains, where it is called Tronador.

DENTELLA REPENS, Forst. Char. Gen. 26, t. 13. A well known species of Southern Asia and Australia. Growing about Acapulco in ravines or in moist shaded walls of houses, November, 1894 (no. 65).

Genipa (?) cinerea. A loosely branching shrub, with the cinereous bark minutely pubescent: leaves clustered at the ends of the subhorizontal branches: spines 1 or 2 (or 0) toward the tips of the branches, thickish at base, 6 to 9 mm. long: stipules broadly ovate, obtuse, 7 mm. long, puberulent without, pilose within, somewhat persistent: leaves coriaceous on dilated petioles 2½ to 4 cm. long, ovate or obovate, obtusish at the tip, acute or obtuse at the base, 5 to 15 cm. long, 4 to 9 cm. broad, short-pubescent and dull above, cinereous beneath with somewhat woolly hairs; veins prominent beneath: fruit apparently 1-celled, obovate, 7 cm. long (including the short oblong beak), 5 cm. broad; the firm rind 4 mm. thick, with 6 or 8 prominent longitudinal ribs, and many irregular secondary ones, somewhat warty, the outer surface soft-pubescent with short cinereous hairs, the inner surface straw-colored and shining: seeds very many, brown and shining, oblong or suborbicular, about 1 cm. long, thin and slightly concave on one side; the thin testa tending to separate on the edges from the horny albumen; embryo plane, the terete radicle nearly 2 mm. long, the reniform cotyledons about as broad. — Growing among other plants for support in the high mountains near Acapulco, January, 1895 (no. 348). Doubtfully referred to this genus. The apparently 1-celled fruit seems to place it with *Genipa*, but the spinose branches and horny albumen are more characteristic of *Randia*. The seeds are apparently good, and flowering plants may possibly be secured for further study.

Montanoa Palmeri. Large upright shrub with habit of the *Elder*, 2 to 2½ m. high: branches terete, fuscous, striate, marked with lenticels, glabrous: branchlets tomentulose: leaves ample, opposite, slender-petioled, rhombic, crenate, 10 or 12 cm. long, 7 or 8 cm. broad, caudate-acuminate, with a single strong angle or short lobe on each side, 5(–7)-nerved from very near the base, roughish above, slightly paler and tomentulose beneath; the uppermost leaves ovate, crenate but not lobed: corymb ample: bracts linear: heads 1 cm. in diameter: scales of involucre lance-oblong, acute, silky-villous, 6 mm. long: disk-flowers 10 to 12, with tube shorter than the throat; ray-flowers 5; rays white, 6 or 7 mm. long, two thirds as broad: chaff very woolly and with slightly pungent at length recurved tips. — Collected on hillsides near Acapulco, November, 1894 (no. 44). The white flowers have a strong fragrance suggesting apple blossoms.

Encelia tenuis. A very slender plant with puberulent and sparingly hispidulous stems, nearly naked above and producing few-headed panicles: leaves mostly opposite, deltoid-ovate, subcordate, 4 to 7 cm. long, coarsely and irregularly dentate, scabrous on both surfaces, on short slender petioles, subtended by connate suborbicular foliaceous appendages: involucre oblong-cylindrical, 9 mm. high, with 2 or 3 series of puberulent and ciliate lance-acuminate bracts, the outer series much shorter than the inner: rays 8 or 10, sulphur-yellow, 5 mm. long: bracts of the receptacle silky-villous, especially along the backs and toward the acuminate tips: akenes obcordate-ovate, 5 mm. long, appressed-silky, awnless. — Rather scarce on the edge of a cornfield, Acapulco, November, 1894 (no. 96).

BIDENS REFRACTA, Brandegee, Zoe, i. 310. Two plants found in a shady river bottom, November, 1894 (no. 205).

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF NICKEL.

FIRST PAPER. — THE ANALYSIS OF NICKELOUS BROMIDE.

By Theodore William Richards and Allerton Seward Cushman.

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Presented June 9, 1897.

Introduction.

Of the atomic weights to-day those of nickel and cobalt are among the most interesting, not only because the two values are so close together, but also because the purely elementary character of these metals has been recently doubted.* A careful study of the available literature upon the subject leaves the impartial critic in grave doubt as to the true values to be accepted, hence an experimental revision seems to be imperative; and the present work is a part of a comprehensive attempt to conduct such a revision. The very useful and complete index of the work which has been done upon this subject, recently published by Professor Clarke,† makes a detailed statement of the various researches unnecessary here; but a chronological list is appended.

The Atomic Weight of Nickel.

$O = 16$.

1826.	By Analysis of Chloride.	
	Rothoff	59.1
1852.	Reduction of the Oxide by Hydrogen.	
	Erdman and Marchand	58.2–58.6
1856.	Conversion of Nickel to Sulphate.	
	Deville	58.85
1857.	Analysis of the Oxalate.	
	Schneider	58.07
1858.	Analysis of the Sulphate and Chloride.	
	Marignac	58.4–59.29

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* Zeit. Anorg. Chem., II. 235; Berichte d. d. ch. Gesell., 1889, pp. 11, 2026.

† Recalculation of the Atomic Weights, Smithson. Misc. Coll., Constants of Nature, Part V., 1897, p. 291.

1860.	Synthesis of the Chloride.	Dumas	59.02
1863.	Reduction of the Oxides in Hydrogen.	Russell	58.74
1866.	Analysis of Nickel Potassic Sulphate.	Sommaruga	58.03
1867.	By relation to Gold, out of Sodic Auro-chloride.	Winkler	59.45
1867.	Measurement of Hydrogen evolved by acting on Nickel with HCl.	Russell	58.77
1871.	Analysis of Strychnine and Brucine Nickelo-cyanides.	Lee	58.01
1883.	Analysis of the Sulphate.	Baubigny	58.73
1886.	Reduction of Oxide (NiO) by Hydrogen.	Zimmermann	58.71
1890.	Reduction of Oxide by Hydrogen.	Mond, Langer, and Quincke	58.58
1892.	Conversion of Sulphate to Oxide, and Reduction in Hydrogen.	Schützenberger	58.54
1892.		Krüss and Schmidt	57–64
1893–94.	Analysis of Nickelous Chloride and by relation to Iodine.	Winkler	59.05–58.87

Value accepted by Ostwald,* 1890 . . . Ni = 58.5
" " Clarke,† 1896 . . . Ni = 58.687
" " Seubert,‡ 1896 . . . Ni = 58.9

A glance at this list shows the lack of consistency in the results obtained. In many cases this is sufficiently accounted for by the inadequacy of the methods, and the known impurity of the materials used, without taking into consideration the unconfirmed admixture of unknown impurities. A critical investigation of the data already published would be an endless and perhaps unprofitable labor, and we prefer at this time rather to record the method and results of our own work than to enter into any discussion of claims heretofore advanced.

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* Lehrbuch, Vol. I. p. 96.

† Recalculation of the Atomic Weights, *loc. cit.*

‡ Zeitschr. Anorg. Chem., XIII. 229.

While it is obvious that certainty is to be obtained only by securing unanimous results from a number of compounds and methods, it is equally obvious that a single method, well worked out, is far better than twenty incomplete ones; hence the present work was confined for the present to a single compound.

In our choice of material, we were guided by experience already gained in this Laboratory. The advantage of the bromides as typical compounds in atomic weight determinations has been discussed by one of us in preceding publications, and requires no further mention. The rather meagre current descriptions of the properties of anhydrous nickel bromide did not seem encouraging, but the progress of the research showed that it is possible to dry this salt, weigh it, and dissolve it in water in a perfectly normal condition. Since this was the case, nickelous bromide was naturally chosen as our starting point.

THE PREPARATION AND PROPERTIES OF NICKELOUS BROMIDE.

Finely divided nickel, when heated to a red heat in a stream of dry bromine vapor, readily forms the bromide, which sublimes at bright redness. The color of the sublimate varies from a pale straw-yellow to a dark bronze-brown, according to the state of aggregation. At a red heat in the presence of traces of air or moisture, the salt loses traces of bromine with the formation of bright green nickelous oxide, unless much hydrobromic acid is present. We have never obtained evidence that an oxybromide is formed under these conditions.

The sublimed bromide is almost insoluble in cold water, but solution soon becomes apparent to the eye in water at 50°. In water at 90° the salt dissolves less slowly, but a gram still requires an hour or two for its complete solution. When originally free from oxide, the sublimed bromide dissolves in water even at the boiling point to form a solution of perfect clearness. According to Berthemot,* a solution of nickelous bromide left for some time in contact with air deposits some flakes of the oxide. We have never met with the slightest evidence of the truth of this statement in the case of a dilute solution. If, however, the nickelous bromide contained only a slight admixture of the oxide, this oxide might escape observation until it had settled out upon the bottom of the vessel. Dilute nitric acid does not materially hasten the solution of the bromide. The sublimed crystalline salt is hygroscopic in character, although not nearly to the extent which we had been led to expect. From several experiments carried out to test this point it appeared that freshly sublimed nickelous bromide exposed to the free air of the room absorbed about 0.1 milligram per gram in ten minutes.

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* Anal. Chim. Phys., [2.], XLIV. 389.

Since the value of the selection of nickelous bromide as the starting point in the determination of the atomic weight of nickel depends on the possibility of dissolving the salt in hot water without the slightest loss of bromine, it seemed necessary to investigate this point. To this end, a mass of several grams of the sublimed compound was suspended in a flask arranged in such a way that the atmosphere of the flask during the solution could be swept through a bulb-tube containing a mixture of potassic iodide and starch. Any formation of nickelous oxide or oxybromide during the heating of the solution could have taken place only by disengagement of bromine, which would have been shown by the blueing of the indicator in the bulb. Not the slightest tinge of blue color appeared at any time during the experiment, in spite of the fact that the solution of nickel bromide was finally subjected to prolonged boiling. That the iodo-starch mixture was exceedingly sensitive to very minute traces of free bromine was assured by experiment in the first place. This experiment is detailed here, however, merely as corroborative testimony, and is not advanced as being final on the subject; the best evidence is yielded by the quantitative results of our series of analyses.

Being now sure that we could analyze the salt if we could obtain it in a pure state, we next proceeded to determine whether it could be prepared in a condition altogether suitable for weighing and analysis. The first sublimations were performed in an ordinary combustion tube in an atmosphere of carbon dioxide. These sublimations yielded in no case material that was above suspicion, and none of it was used in our analyses, the experiments being carried out merely as a study of the properties of the substance under examination. Since it seemed possible that the carbon dioxide used might suffer partial dissociation at the high temperature necessary for the sublimation, nitrogen was substituted for this gas. After many experiments with nitrogen, both alone and when mixed with bromine vapor, it was found best to carry on the sublimation of the nickelous bromide in a stream of nitrogen mixed with hydrobromic acid. The elaborate apparatus constructed by Mr. G. P. Baxter for supplying suitable mixtures of any or all of these gases and vapors for preparing and subliming the salt will be described in a later paper, upon the atomic weight of cobalt.

The temperature at which the salt sublimes lies not far from that at which the hardest glass begins to soften, hence we found it advantageous to conduct the sublimation in porcelain. In order to collect the product a small porcelain tube, used as the receiver, was fitted, telescope fashion, inside of the larger tube containing the substance to be vaporized. In this way the pure crystals could be removed without contamination. Since nickelous bromide is decomposed either by oxygen or by water at a red heat, unless a very large excess of hydrobromic acid gas is present, both oxygen and water must be excluded with scrupulous care during its final sublimation. At first we were not able to accomplish this complete exclusion, so that most of the bromide used in the preliminary series of analyses contained traces of green crystalline oxide, which were carefully collected and weighed. In making the final calculation, the weight of this oxide was subtracted from the total, in order to obtain the weight of the bromide. Subsequently, with improved apparatus, the bromide was obtained in a state of satisfactory purity; it gave a perfectly clear solution in water, leaving nothing to be desired. With the improved arrangement the oxide itself was quickly converted at a dull red heat into the bromide, by means of a stream of hydrobromic acid gas. Hence it was possible to purify nickelous bromide contaminated with oxide by simply treating it for a few minutes in this fashion; in practice, the scheme worked very well.

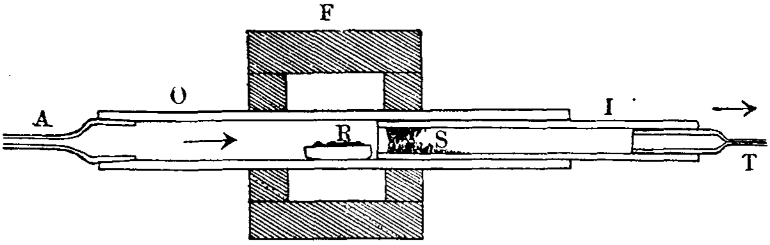

Fig. 1. Section of Apparatus for Sublimation.

A = glass tube for admitting bromine vapor. O = outer porcelain tube. I = inner porcelain tube. T = glass outlet tube. F = perforated Fletcher furnace. R = boat containing nickel. S = Sublimed bromide.

Chemical literature contains no satisfactory determination of the specific gravity of the anhydrous salt; hence, in order to reduce our weighings to the vacuum standard, the following determination was made. 3.3196 grams of pure dry nickelous bromide displaced upon one occasion 0.6162 gram and upon another 0.6156 gram of rectified toluol at 28°. Since the specific gravity of the toluol at this temperature was 0.860, referred to water at the same temperature, the specific gravity of the bromide must be 4.64. Nickelous bromide is insoluble in toluol.

PURIFICATION OF MATERIALS.

Nickel. — Since the possibility of preparing and analyzing pure nickelous bromide had now been proved, the next step was to purify all the materials concerned in its manufacture. First among these materials comes nickel, which must not only be freed from all known impurities, but must also be so treated as to detect and eliminate unknown ones. With this latter purpose in view, our material was obtained from two distinct sources; first, the "pure" nickel of commerce; and, secondly, really pure nickel (containing only a little iron) prepared by Dr. Mond through the carbonic oxide process and kindly presented by Dr. Wolcott Gibbs.

It is convenient to consider first our treatment of the commercial nickel. In proceeding with the further purification of this sample, our first step was to remove the metals of the copper and tin groups. The simple treatment with hydric sulphide has generally been considered sufficient to insure the separation of the metals of these groups, in spite of the fact that many of the sulphides when present in small quantities often assume a colloidal condition in which they cannot be separated by filtration. In our case this difficulty was avoided by regulating the acidity of the solution so that a certain amount of black nickelous sulphide was precipitated, which effectually "swept" this liquid, coagulating small quantities of foreign sulphides. After filtration the liquid was boiled to drive off the hydric sulphide, oxidized with a few drops of nitric acid, made alkaline with ammonia, and filtered. The precipitation of the sulphide was now continued by the passage of a little washed hydric sulphide. This first comparatively small amount of sulphide was filtered out and discarded. The remaining nickel was then as nearly as possible completely precipitated in the form of sulphide. After the precipitate had been allowed to settle in a closed flask over night, the liquid was decanted, and the precipitate was washed by decantation many times with boiling water until neutral. Cold dilute hydrochloric acid was now added, and the precipitate was digested for several days. Since the color of the supernatant liquid showed that a slight amount of even the comparatively insoluble nickel sulphide had gone into solution, the assumption was not unreasonable that nearly, if not quite, all of the more soluble sulphides must have been removed. The black precipitate was now repeatedly washed with hot water until the washings were quite neutral; it was next dissolved in strong hot hydrochloric acid, and after the separated sulphur had been removed, the solution was evaporated to dryness, and the residue was taken up with water. The material was now considered fairly free from its usual impurities, with the single exception of cobalt.

In commenting on the work of an early experimenter upon the atomic weights of nickel and cobalt, Clarke has objected that "his results are entitled to no especial weight at present, since it cannot be certain from any evidence recorded that the oxide of either metal was absolutely free from traces of the other." * Since the two metals have atomic weights only differing at the outside by half a unit, "traces" of one in any preparation of the other metal could not alone furnish a reason for invalidating the results. Nevertheless, for our purpose it seemed desirable to prepare nickel as nearly free from cobalt as possible. In order to attain this end with any degree of certainty, it is obvious that a qualitative test must be found that should show with sufficient accuracy the presence or absence of cobalt. Winkler † has recommended a test for which he claimed greater accuracy than the better known method with potassium nitrite. The moderately dilute solution of nickel is treated with ammonia until a clear blue color is obtained and then one or two drops of potassic permanganate are added. If no cobalt is present, the blue solution of nickel takes on a purple tinge; whereas cobalt, if present, reduces the permanganate. Winkler does not state the dilution of the permanganate solution, or how much should be added, although manifestly the degree of refinement of the test depends on these points. The permanganate solution which worked well with us contained one gram of the salt in a litre. To the dilute solution of nickel to be tested, contained in a color-comparison apparatus, enough ammonia is added to render the solution a light sky-blue, and then one tenth of a cubic centimeter of the permanganate is dropped in. Under these conditions, the mixture appears decidedly purplish in hue, if cobalt is absent. Of course the test is of value only in the absence of any foreign substances having either a reducing or an oxidizing action on permanganate. We have found it possible by this method to detect one part of cobalt in twenty-five hundred parts of nickel, an amount of impurity which could cause a final error in the atomic weight of only one part in five hundred thousand.

Anthon's process ‡ for eliminating cobalt was adopted for the purifica-

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* Recalculation, 1897, p. 291.

† Zeitschr. Anal. Chem., VI. 20.

‡ See Dammer, Anorg. Chem., III. 490.

tion of our sample. The nickel was twice fractionally precipitated as hydroxide by means of pure sodic hydroxide, the mixture being thoroughly boiled. As far as our test could show it, all the cobalt remained in the filtrate, the last precipitate being contaminated only with a small amount of alkali.

When ammonia is added to a solution of nickelous bromide, a beautiful violet crystalline compound is formed, having the formula $NiBr_2 . 6NH_3$, according to our analyses as well as those of Rammelsberg.* Since this compound is characteristic of nickel, and similar compounds are not formed by cobalt or most other metals under similar circumstances, and since it is soluble in strong hot ammonia water, but almost insoluble in cold ammonia, it affords a very convenient and effectual means of purifying nickel preparations. Our purified oxide was hence dissolved in pure hydrobromic acid, ammonia was added in excess, and the mixture, contained in a platinum flask, was cooled to zero. The beautiful purple precipitate was collected upon pure filter paper and was washed with strong ammonia. All the material used in the analyses was passed through this treatment at least once, although the various samples were subsequently subjected to different methods of further treatment which will be described in each case.

The violet compound made from our first sample of purified nickel was treated with an excess of water and boiled in a platinum dish, a proceeding which completely precipitated the nickel as hydroxide. The greenish mass was thoroughly washed, and was then dissolved in hydrobromic acid. The nickelous bromide thus obtained was dried in a vacuum desiccator over dry soda; but even after this treatment it was found to have retained considerable quantities of water, an impurity which greatly increased the difficulties of sublimation. Hence this sample, numbered I., was used only for two preliminary analyses.

Another portion of this same sample of the violet compound was recrystallized several times in succession by cooling its hot ammoniacal solution. The resulting magnificent crystals were dissolved in water and the solution was boiled to drive off the ammonia. The precipitation being thus accomplished the basic hydroxide was collected, carefully washed, dried, and ignited over an alcohol flame in a porcelain vessel. The resulting nickel oxide was reduced to the metal by igniting this material, held by a porcelain boat in a combustion tube through which a current of pure dry ammonia gas was passing. The spongy nickel thus produced was changed to bromide and sublimed in the manner already described. The pure substance thus prepared is designated below as number II.; it also served for two of the earlier analyses.

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* Pogg. Anal., LV. 243.

The further purification of the sample of nickel obtained by the process of Mond, Langer, and Quincke, at first proceeded exactly in the steps just described; except that no attempt was made to remove cobalt, since none was present. After it had reached the stage of treatment represented by the last hydroxide obtained above, the material was converted into the sulphate and subjected to electrolysis out of an ammoniacal solution in a platinum dish. The object of this procedure was of course to free the nickel still more effectually from the alkalies, silica, and many other impurities which are not precipitated on the cathode. The bright heavy deposit of pure nickel was dissolved, with a great deal of difficulty, in redistilled strong nitric acid; and the excess of acid was driven off by evaporation. Ammonia and a large excess of pure water were now added, and the solution was boiled until the basic hydroxide was completely precipitated. This was subsequently changed to metallic nickel and then into the sublimed bromide, in the manner already described, and the resulting material, labelled III., served for a large number of analyses. A small portion of it, that used for Experiment 8, was resublimed.

The sample of material used for the final analyses was even more carefully purified than this, however. A quantity of the pure nickelous oxide of about the grade of purity of sample III., coming originally from the Mond nickel, was dissolved in sulphuric acid, and the solution was made alkaline by passing in pure ammonia gas, in a platinum dish. When most of the nickel had been deposited electrolytically from this solution, the portion remaining in the electrolyte was thrown away. The bright coating of nickel was washed, pure dilute sulphuric acid was put into the dish, and with reversed poles a strong current was sent through the solution until nearly but not quite all of the nickel was dissolved. The solution was then decanted into another dish, ammonia was passed in until the precipitate formed had redissolved, the poles were again reversed, and then nickel was once more almost all deposited. This cycle of operations, which gives an excellent method of fractionation, was repeated three times. The final deposit of nickel was dissolved by filling the platinum dish with pure dilute nitric acid and reversing the poles. Only one who has tried dissolving a deposit of nickel on a platinum dish, even in strong nitric acid, can appreciate the ease, cleanliness, and convenience of this method of procedure. The solution of nickel nitrate thus prepared was concentrated by evaporation, and ammonia was passed in until a mass of crystals of the blue ammonio-nickel nitrate was formed. After the mother liquor had been poured off, the crystals were washed with pure ammonia water, and were finally boiled in an excess of pure water in the same platinum dish. The resulting basic hydroxide was then changed to spongy nickel and nickelous bromide in the usual fashion, bearing the title No. IV.

Thus, while all of our samples of nickelous bromide analyzed had been sublimed, the several samples had received previous to sublimation very varying treatment. The fourth had been put through a process of purification far more searching than the first, which had merely been freed from the ordinary known impurities. Hence the essential identity of the results obtained from these several samples is very striking.

Purification of other Materials. — Silver was purified exactly in the manner described by Richards and Parker,* in a recent paper upon the atomic weight of magnesium. The electrolytic crystals were finally fused upon a boat of pure lime in a vacuum. For further details the above mentioned paper should be consulted.

With the co-operation of Mr. Baxter, bromine was purified in a preliminary fashion by solution in strong aqueous calcic bromide, and a subsequent separation. Carefully washed red phosphorus was used to convert the bromine thus obtained, after it had been several times redistilled, into hydrobromic acid; and the hydrobromic acid was freed from iodine and organic matter by several fractional distillations with bromine water. From this pure hydrobromic acid, bromine was obtained by means of manganese dioxide free from chlorine. 2.10289 grams (in vacuum) of silver yielded 3.66066 grams (in vacuum) of argentic bromide on combination with this bromine, — a ratio of 57.445 : 100.00. Mr. Baxter found 57.444 in a similar experiment, while Stas's value was 57.445; hence the purity of our bromine and silver was proved.

Sodic hydroxide was freed from most metallic impurities (iron, etc.) by electrolysis. Ammonia was redistilled in platinum vessels, as were also nitric, and hydrochloric acids. Sulphuric acid was distilled in glass, alkalies being a less dangerous impurity than platinum in the instances where it was used. Water was purified by distillation first from alkaline permanganate solution, and then with a trace of acid potassic sulphate.

In processes where the presence of bromine rendered the use of platinum impossible, Jena glass, or at high temperatures Berlin porcelain, was used. For some of the platinum and other apparatus we are indebted to the Cyrus M. Warren Fund for chemical research in Harvard University.

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* These Proceedings, XXXII. 62.

THE METHOD OF ANALYSIS.

Turning now to the method of analyzing the carefully prepared nickelous bromide, it is obvious that the first point to be considered is the accurate determination of the weight of the salt to be analyzed. This process was effected by means of apparatus similar to that devised for the drying and weighing of magnesic chloride, and described in a recent paper by Mr. H. G. Parker and one of us,* upon the atomic weight of magnesium. In this apparatus, constructed wholly of glass by Mr. Baxter, the bromide under consideration, contained in a platinum boat, was ignited at about 400° in a stream of mixed nitrogen and hydrobromic acid until constant in weight. It was then allowed to cool in a stream of pure dry nitrogen; and when cool it was pushed in pure dry air into its weighing bottle, which was immediately closed by a mechanical device. In this fashion it is possible to dry and weigh accurately the most hygroscopic of substances; and repeated ignitions of the same specimen have shown that perfect constancy in weight may thus be obtained. It is hard to believe that any water is retained by nickelous bromide at 400°; and certainly none could be absorbed during the cooling, for the whole apparatus was shut off from the outside air, and all the gases admitted were first passed through phosphoric oxide.†

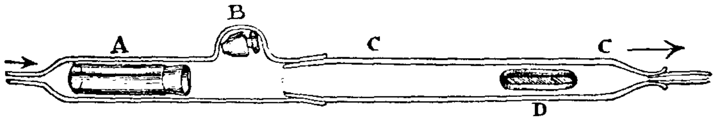

FIG. 2. BOTTLING APPARATUS, HORIZONTAL SECTION.

A = weighing bottle. B = stopper of bottle. CC = hard glass tube.
D = Platinum boat containing nickelous bromide.

The bromide in question was then weighed by substitution, using as the tare to be substituted a weighing bottle precisely like the one containing the platinum boat and substance. In this way alone can the weight of a large bottle be determined within the fraction of a tenth of a milligram. The balance has already been described in detail;* the weights were of course compared and standardized with great care, and were used for no other work during the progress of this.

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* These Proceedings, XXXII. 58.

† A detailed description of this apparatus will be given in the following paper, upon Cobalt.

Having been weighed with accuracy, the nickelous bromide was dissolved in pure warm water in a flask, and from this was transferred to the large beaker flask in which the precipitation was to take place. The platinum boat in which the salt had been treated remained invariable in weight, showing that it had not been attacked by hydrobromic acid at a high temperature.

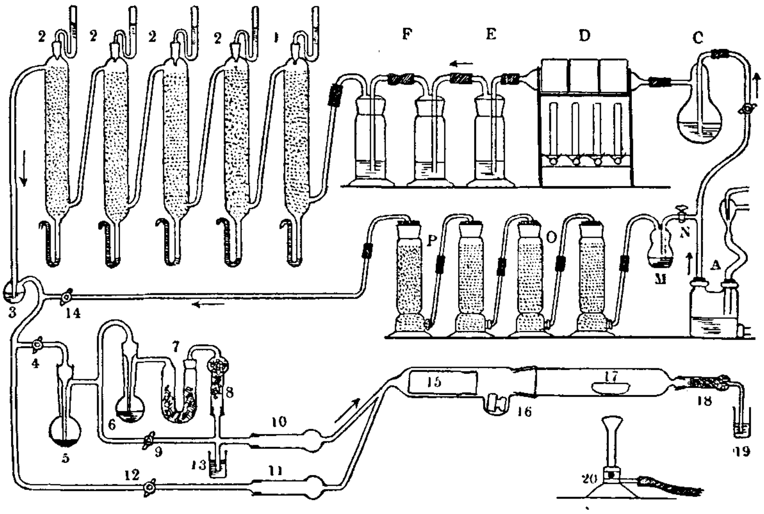

FIG. 3. APPARATUS FOR IGNITING NICKELOUS BROMIDE IN ANY DESIRED MIXTURE OF GASES.

The use of rubber was confined to the first part of this train, where it could do no harm (A B C D E F and A M N O P).

As has been said already, the salt used in the preliminary series was contaminated with a small amount of nickelous oxide, which was filtered off and weighed. The amount of this impurity is given simply to show that the slight irregularity of the results was not dependent upon the adulteration; the weights of nickelous bromide given are those left after the subtraction of the weight of the oxide. All the bromine contained in the solution was precipitated in these seven analyses by means of an excess of argentic nitrate, and the argentic bromide was collected and weighed with the usual precautions.

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* These Proceedings, XXVI. 242.

When the manipulation had thus been mastered, the art of preparing absolutely pure nickelous bromide had been perfected (see Analysis 7), and the atomic weight of nickel had been approximately determined, the method of procedure in subsequent analyses was changed. The now perfectly clear solution was treated with just enough argentic nitrate, prepared from the purest weighed silver, to complete the precipitation. The mean between the two possible end points was determined by titrating backwards and forwards with hundredth normal argentic nitrate and hydrobromic acid solutions;* and thus was determined the ratio of silver to nickelous bromide entitled Series III. After this end point had been determined, a slight excess of argentic nitrate was added to the solution, and the whole was violently shaken. The precipitate was collected upon a Gooch crucible, washed with water containing a trace of argentic nitrate, later with pure water, and finally dried and weighed. The traces of asbestos carried away by the wash water were of course determined, and all the usual precautions were taken to insure great accuracy. Thus was obtained the series of results given in Series II.

THE ATOMIC WEIGHT OF NICKEL.

O = 16.000; Ag = 107.93.

FIST SERIES (PRELIMINARY). RATIO = 2 AgBr : $NiBr_2$.

Number of Experiment.	Sample of $NiBr_2$.	Weight of Nickelous Bromide in Vacuum.	Weight of Insoluble Residue.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Nickel.
		grams.	milligrams.	grams.	
1	I.	2.26113	3.22	3.88769	58.646
2	I.	2.80668	7.08	4.82431	58.708
3	II.	1.41317	3.05	2.42880	58.716
4	II.	1.71759	0.88	2.95307	58.650
5	III.	2.48565	5 24	4.27357	58.651
6	III.	4.32997	15.83	7 44280	58.700
7	III.	2 18072	0.00	3.74856	58.693
		Average			58.680

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* For the details see These Proceedings, XXX. 384.

SECOND SERIES: RATIO = 2 $AgBr : NiBr_2$.

Number of Experiment.	Sample of $NiBr_2$.	Weight of Nickelous Bromide in Vacuum.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Nickel.
		grams.	grams.	
8	III.	3.28039	5.63892	58.691
9	III.	2.70044	4.64208	58.686
10	III.	3.38230	5.81391	58.698
11	III.	1.33459	2.29435	58.670
12	IV.	1.25054	2.14963	58.693
13	IV.	1.32278	2.27384	58.690
14	IV.	2.24452	3.85805	58.705
			Average	58.690

THIRD SERIES: RATIO = 2 $Ag : NiBr_2$.

Number of Experiment.	Sample of $NiBr_2$.	Weight of Nickelous Bromide in Vacuum.	Weight of Silver in Vacuum.	Atomic Weight of Nickel.
		grams.	grams.	
8	III.	3.28039	3.23910	58.701
9	III.	2.70044	2.66636	58.709
10	III.	3.38230	3.33990	58.689
11	III.	1.33459	1.31787	58.689
12	IV.	1.25054	1.23482	58.698
13	IV.	1.32278	1.30629	58 675
14	IV.	2.24452	2.21652	58.676
			Average	58.691

In the table above, the first column records the number of the experiment, the second records the number of the sample of nickelous bromide used, while the third records the weight of this salt taken. The extreme right hand column contains the atomic weight of nickel computed from the values contained in the one just to the left of it, and those contained in the third.

A very interesting evidence of the accuracy of these results is the relationship between the amount of silver taken and the amount of argentic bromide obtained. From the second and third series, we find that 15.51556 grams of nickelous bromide yielded 26.67078 grams of argentic bromide, requiring 15.32086 grams of silver. This leads to the inference that argentic bromide contains 57.444 per cent of silver, a quantity which agrees essentially with the value 57.445 per cent found by Stas. Since the bromine used had been already found to be free from other halogens, and the silver was known to be perfectly pure, we have in these results conclusive proof that no nickel salt was occluded by the argentic bromide, as well as a satisfactory "check" upon the accuracy of the work.

When we examine the results with respect to the various samples of the salt analyzed, we find a very interesting and satisfying uniformity. The four samples of nickelous bromide gave the following results for the atomic weight of nickel: —

Sample I.	58.677
Sample II.	58.683
Sample III.	58.688
Sample IV.	58.689

The slight rise in the value with increasing purity is not large enough to have any weight, for there are analyses in the lowest series giving higher individual results than any in the highest series. Hence we are forced to the conclusion, that the least carefully purified specimens of nickelous bromide must have been essentially identical with the most carefully purified. The chances are evidently exceedingly small that the impurities would so combine as exactly to counterbalance one another.

The further discussion of this important question will be reserved until more experimental work has been done. For the present, it is our opinion, at this first halting place in a long investigation, that the atomic weight of nickel cannot be far from 58.69 if O = 16.00, or 58.25 if O = 15.88.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY
OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF COBALT.

FIRST PAPER. — THE ANALYSIS OF COBALTOUS BROMIDE.

By Theodore William Richards and Gregory Paul Baxter.

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BY THEODORE WILLIAM RICHARDS AND GREGORY PAUL BAXTER.

Presented June 9, 1897.

INTRODUCTION.

SIMULTANEOUSLY with the work described in the preceding paper, a similar investigation of cobalt was in progress. Earlier work upon this metal had led to results quite as incapable of ready interpretation as those concerning nickel; even very recent work upon the atomic weight of cobalt allows a range of much over a unit (from 58.78 to 60.1) as the possible field within which the truth may lie. Professor Clarke has given a full summary of all the available data upon this subject in his recent work * upon the Recalculation of the Atomic Weights, and for references and details the reader is referred to this useful volume. A chronological list is reprinted here merely to show how urgent is the need for further labor.

EARLIER WORK ON COBALT.

($O = 16.$)

			Atomic Weight.
1826.	Rothoff	$CoO : 2\ AgCl.$	58.50
1857.	Schneider	From cobaltous oxalate	60.00
1858.	Marignac	$CoSO_4 : CoO$	58.76
1858.	"	$CoCl_2 : 2\ Ag$	58.85
1860.	Dumas	$CoCl_2 : 2\ Ag$	59.09
1863.	Russell	$CoO : Co$	58.74
1867.	"	$Co : H_2$ (measured)	59.08

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* Smithsonian Miscellaneous Collections, Constants of Nature, Part V. p. 291.

			Atomic Weight.
1866.	Sommaruga	$Co_2(NH_3)_{10}Cl_6 : 2\ Co$	59.95
1867.	Winkler	3 Co : 2 Au	59.42
1868.	Weselsky	From complex cyanides	59.13
1871.	Lee (under W. Gibbs)	" " "	59.20
1871.	" " "	$Co_2(NH_3)_{10}Cl_6 : 2\ Co$	59.16
1886.	Zimmermann	CoO : Co	58.89
1889.	Winkler.		
1891.	Remmler	CoO : Co	58.80
1892.	Schützenberger	CoO : Co	60.12
1893.	Winkler	Co : 2 Ag : 2 AgCl	59.82
1894.	"	$Co : I_2$	59.52
1895.	Hempel and Thiele	CoO : Co	58.99
1895.	" "	$Co : Cl_2$	58.78
1895.	" "	Co : 2 AgCl	58.91

From these absurdly varying results, Clarke * computes the value 58.932 as the most probable atomic weight, while Seubert † selects 59.6, and Ostwald ‡ 59.0, as the true value. Of course, many of the figures above may be thrown out at once; but the evidence which remains after this first elimination is still too vague for anything like scientific certainty. It is not the purpose of the present work to discuss the accuracy of these bygone investigations; for such discussions are apt to be unconvincing. Inattention to a single matter of detail may easily overthrow all the value of quantitative labor; a post-mortem examination is not always able to detect the more subtle poisons. Our object is rather to accumulate a mass of data which we thoroughly understand, and then to interpret these data with regard to the probable chemical errors which may have crept into them. The present paper is only the first one of an investigation which we hope to continue until we have solved the problem.

The advantages to be gained by a simultaneous investigation of nickel and cobalt are obvious. Although the similarity of the two metals is usually overrated, it is still convenient to consider them together. Evidently much time may be saved in the preparation of materials if two similar researches are conducted side by side; and evidently the experience gained in one may be immediately helpful in the other. Fortunately, cobalt, like nickel, yields a bromide which is readily obtained anhydrous

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* *Loc. cit.*

† Zeit. Anorg. Chem., XIII. 229.

‡ Lehrbuch, Vol. I. p. 79.

in a state of great purity, and this metal therefore joins the ranks of those elements whose atomic weights may be determined by reference to silver through the most satisfactory of all processes of precipitation.

THE PREPARATION AND PROPERTIES OF COBALTOUS BROMIDE.

All the cobaltous bromide used in this research was prepared by passing bromine vapor over hot spongy cobalt. The sublimation of the salt is much less troublesome than that of the corresponding salt of nickel. The bright green anhydrous crystals of cobaltous bromide are very much less easily decomposed than the brown nickel compound by water or oxygen at a high temperature, in spite of the fact that cobaltous bromide is very much the more hygroscopic and soluble in water when cold. In no case was a trace of an oxide of cobalt found among the crystals of bromide used for the analyses.

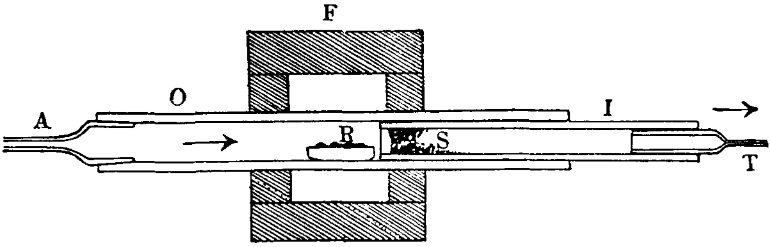

FIG. 1. SECTION OF APPARATUS FOR SUBLIMATION.

A = glass tube for admitting bromine vapor. O = outer porcelain tube. I = inner porcelain tube. T = glass outlet tube. F = perforated Fletcher furnace. R = boat containing cobalt. S = Sublimed bromide.

The first experiments were carried on in a hard glass tube heated by a "combustion" furnace, but as the high heat necessary to volatilize cobalt bromide played sad havoc with the glass, porcelain tubes, heated by means of a perforated Fletcher furnace,* were substituted. The arrangement was similar to that used in the research upon nickel. Into one end of a large porcelain tube (of which the internal diameter was 28 millimeters) was ground a glass connector fused to the apparatus for supplying a mixture of bromine vapor, hydrobromic acid, and nitrogen; while inside of the other end was "telescoped" a closely fitting smaller porcelain tube designed to serve as the receiver of the sublimed material.

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* These Proceedings, XXXII. 63.

The boat containing the cobalt was of course placed in the hottest part of the furnace, and the open end of the inner tube was adjusted just beyond this point. At first, the glaze of the receiver tube was attacked by the hot bromine and bromides, and the first sample of sublimate was found to be contaminated by the decomposition products of the glaze. Later the porcelain became covered with a brilliant-colored coating of a cobalt glaze which seemed to be permanent. The sublimate used in the analyses was taken more especially from the central portions of the sublimed masses, so that even if a small amount of alkali had been extracted from the porcelain it must have remained clinging to the walls of the tube. All the sublimates excepting the very first gave a wholly clear aqueous solution.

As has been already stated, anhydrous cobaltous bromide thus prepared consists of brilliant green crystalline plates, which quickly absorb water from the air to form the pink hydrated salt, and dissolve with great ease in cold water.

The specific gravity of anhydrous cobaltous bromide being unknown, the following experiments were made to determine it. (a). 2.0915 grams of the salt which had been dried at about 200° displaced 0.3285 gram of kerosene (dried over soda and redistilled) at 25°. (b). 1.3965 grams of the salt displaced 0.2186 gram of kerosene. The kerosene, which was used in this case because cobaltous bromide was found to be slightly soluble in toluol, had at 25° a specific gravity of 0.7698 referred to water at 4°. Hence we have for the specific gravity sought, (a) 4.901, (b) 4.917. The mean of these two values is 4.909.

Since brass weights were employed, in order to correct the weights of cobaltous bromide found in air during the subsequent accurate analyses to that which would have been observed in a vacuum, 0.00010 gram should be added for each gram of this material. In the same way 0.000045 gram must be added to every apparent gram of argentic bromide, and 0.000031 gram must be subtracted from every apparent gram of silver. These corrections are all applied below.

The balance used in this research was the one used in those upon copper, barium, strontium, zinc, and nickel: it needs no further description. The weights were of brass, gold plated; they were standardized with great care, and were used for no other work.

PURIFICATION OF MATERIALS.

Cobalt. — The doubt which has been thrown on the elementary character of cobalt by several experimenters led us to the application of unusual care in preparing the material used in this investigation. Pure cobalt was prepared by two entirely different methods; and a third sample was purified by both methods. The agreement of the results obtained from all of these samples leaves no doubt as to the uniformity of the material used.

In the first place about three hundred grams of commercial cobalt chloride were dissolved in a litre of water. The removal of the copper group as sulphides was of course the first step; but on account of the difficulty of filtering out small quantities of these sulphides, the solution was not acidified before passing in sulphuretted hydrogen. In this way enough cobalt sulphide was precipitated to sweep the solution free from small amounts of a precipitate which could not be removed by filtration. After long standing the supernatant liquid was decanted through a filter, and, as the precipitate was found to contain copper, the solution was again fractionated with sulphuretted hydrogen. The sulphides from this precipitation gave no test for copper, hence it is fair to conclude that the filtrate was free from this metal. After the addition of a large amount of hydrochloric acid to this filtrate, and then ammonic hydrate until the mixture was strongly alkaline, pure sulphuretted hydrogen in excess was passed into the solution. The precipitated sulphides were washed several times with water, and then digested with cold dilute hydrochloric acid. The precipitate was then washed free from iron by decantation. As the succeeding purification by means of potassic nitrite was in itself a separation from many other metals as well as from nickel, it was not thought necessary to reprecipitate the cobalt sulphide at this stage. Accordingly the precipitate was dissolved in aqua regia, and after dilution and filtration the solution was evaporated until the greater part of the excess of acid was driven off. Sodic hydrate was then added to the diluted solution in slight excess, and subsequently a large amount of acetic acid. Upon the addition of potassic nitrite all the cobalt was precipitated as the crystalline yellow double nitrite of potassium and cobalt. This precipitate was washed by decantation several times, and after its solution in strong hot hydrochloric acid the precipitation was repeated. The reagents used in this purification were especially tested for calcium; for only in the absence of calcium is the separation of cobalt from nickel complete by this method. The efficiency of the separation is shown by the fact that the filtrate from the first precipitation was distinctly green, owing to the nickel salts present, while the filtrate from the second precipitation after evaporation to small volume merely turned faintly brown on the addition of ammonic sulphide. The double nitrite was again dissolved in hydrochloric acid, and the cobalt was partially freed from alkalis by precipitation as sulphide. The sulphide was then treated with an excess of nitric acid and was heated upon the steam-bath until the resulting cobalt nitrate was free from every trace of chlorine.

In order to free the cobalt from alkalis it was next to be precipitated by electrolysis; and at first we hoped to convert the electrolytic film directly into bromide. However, on passing a galvanic current through the ammoniacal nitrate, an oxy-amine was precipitated in such quantities as to render the use of this electrolyte impossible. Experiments were then made with the ammoniacal sulphate in order to find the conditions most favorable for the deposition of a bright coherent film. The negative electrode was a platinum dish, the positive electrode a flat spiral of platinum wire. The first attempts, which were made in a dish holding 250 cubic centimeters and having an area of 150 square centimeters, with currents from 0.3 to 0.7 ampere, and with solutions of widely varying strengths, resulted in the deposition of dull black films. With a current strength of more than one ampere, however, the film was always comparatively bright. It was found impracticable to use this film directly for conversion into bromide on account of the difficulty of stripping the film from the dish. Accordingly, after being thoroughly washed, it was dissolved in the dish by nitric acid which had been distilled with a platinum condenser; and when the excess of acid had been driven off by evaporation, a slight excess of pure ammonia (made by distilling ordinary pure ammonia into pure water contained in a platinum dish) was added. The resulting green precipitate was washed several times by decantation with the purest water, filtered on a washed filter, dried in a steam oven and finally, after separation from the filter paper, ignited to the black oxide in a platinum crucible. During the ignition this crucible was contained in a porcelain crucible which was heated by an alcohol lamp. Pure metallic cobalt was prepared from this oxide by reduction in a stream of ammonia gas, generated in an apparatus composed entirely of glass and dried by passage over stick-soda. Metallic cobalt is thus obtained in a spongy form, well adapted for its following treatment with bromine, and certainly free from all such impurities as alkalis and silica. The cobalt bromide, prepared from this metal in the manner already described, was labelled No. I.

The second method of preparing pure cobalt was by precipitation as one of its amines. The purpureo-chloride seemed best suited for the present purpose, both on account of the ease with which it can be prepared and because of its comparative insolubility in cold ammoniacal or acid solutions. At first this compound was made by passing a current of air for some time through a solution containing cobaltous chloride, ammonic chloride, and ammonia. A considerable quantity of purpureochloride was formed by this process; and from the solution, by acidification with hydrochloric acid and cooling, fully as much more was obtained. Later another method, capable of giving a much larger yield, was used. Into the strongly ammoniacal solution bromine was dropped slowly. A heavy precipitate resulted, and the solution upon acidification and cooling as above yielded the greater part of the cobalt it contained. Several lots of amines which had been prepared in one or the other of these ways were mixed and dissolved in hot ammonia. After filtering the solution was acidified with hydrochloric acid, with the result that on cooling nearly all the cobalt was reprecipitated. The precipitate was washed by decantation with cold dilute hydrochloric acid, and the whole process of recrystallization repeated. This time the precipitate was collected on a pure filter and dried. After separation from the filter paper it was converted into the sulphates of cobalt and ammonium by heating on a sand bath with sulphuric acid until all chlorine or hydrochloric acid fumes had ceased to come off. From the solution of these sulphates metallic cobalt was prepared by electrolysis, solution in nitric acid, precipitation as hydrate, and reduction, in the manner already described. This preparation was designated as Sample II.

For the final analyses the cobalt was purified by a combination of all the before mentioned methods. The carefully purified cobaltous nitrate from Sample I. was converted into a cobaltamine compound, and this salt was six times recrystallized by solution in ammonia and precipitation with hydrochloric acid. Each time the precipitate was washed twice by decantation with hydrochloric acid, and after the second, fourth, and sixth dissolving the ammoniacal solution was filtered. The final precipitate was converted into spongy metallic cobalt in the usual manner. After sublimation part of the bromide prepared from this cobalt was resublimed to see if this process had any influence on the salt. That which had been resublimed was labelled IV., the other III. The apparatus used for the sublimation has been already described (page 117).

Silver was prepared with great care, according to a method similar to that described in previous papers from this Laboratory.* The only improvement introduced was the removal by means of nitric acid of the surface of the buttons, which had been fused in a vacuum upon a boat of lime. This treatment is of course more thorough and satisfactory than Stas's method of digesting them with hydrochloric acid. The silver was subsequently treated with ammonia, thoroughly washed with water, and dried in a desiccator over soda lime. One large piece was rolled out between clean steel rollers; and the foil, after having been cut into small strips, was cleansed as above described. These fragments made it possible to weigh out any desired amount of the metal.

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* These Proceedings, XXXII. 62.

Bromine was prepared in common with Mr. Cushman. For the method used the paper upon nickel should be consulted.[*] Much experience has led to the conclusion that the method there described is the most satisfactory and convenient means of obtaining pure bromine, since it eliminates organic as well as inorganic impurities. In order to test the purity of the bromine and silver, 2.18679 grams of silver (in vacuum) were dissolved in pure nitric acid and precipitated with a slight excess of ammonic bromide which had been prepared by running the bromine in question into pure ammonia. The silver bromide was collected on a Gooch crucible and afterwards fused in a porcelain crucible. The fused bromide weighed 3.80679 in vacuum, whence the ratio of silver bromide to silver is 100.000 : 57.444. Mr. Cushman, experimenting upon the same sample of bromine, obtained the result 57.445; and since Stas's result was identical with these, there can be no doubt of the purity of our silver and bromine.

The sulphuric acid used in the drying towers was boiled for some time in order to increase its efficiency and to free it from volatile impurities. The phosphoric oxide was proved free from volatile compounds of phosphorus by passing a current of air over a considerable quantity of this substance into aqua regia for several hours. The aqua regia was subsequently found to contain no phosphorus. Distilled water was prepared with all the usual precautions necessary to free it from organic and non-volatile impurities, as well as from ammonia; nitric and hydrobromic acids were purified by repeated distillation with a platinum condenser; great care was taken to exclude dust, as well as the products of the combustion of illuminating gas, from the substances under treatment; platinum vessels were employed wherever it was possible to employ them; and many other precautions, often essential in order to prevent the complicated processes from introducing as much impurity as they removed, were applied. Alkali metals and silica, it will be seen, were among the impurities avoided as much as possible. For several pieces of platinum ware and other apparatus we are indebted to the Cyrus M. Warren Fund for research in Harvard University.

The Method of Analysis.

The most insidious of all impurities in accurate quantitative work is water. Its insidiousness is due to the difficulty of detecting it in small amounts, as well as to its invariable occurrence in the atmosphere and its common use as a solvent and medium for crystallization. Our first analytical problem, in this case just as in the case of nickel, was to weigh the salt to be analyzed in such a fashion as to exclude this ever watchful enemy. The fact that cobaltous bromide is less easily decomposed at high temperatures than is nickelous bromide, tended to make our present problem the easier of the two; but the much greater hygroscopicity of the cobalt salt had the opposite tendency. The apparatus so useful in the cases of magnesium,* zinc, and nickel, proved to be equally serviceable here; cobaltous bromide, after being ignited in a stream of mixed nitrogen and hydrobromic acid, cooled in dry nitrogen, and bottled automatically in dry air, may be weighed with perfect certainty. The bottling apparatus has been described so often that further details are unnecessary here; but the apparatus for supplying the desired gases has not yet been explained in all the complication of its present form.

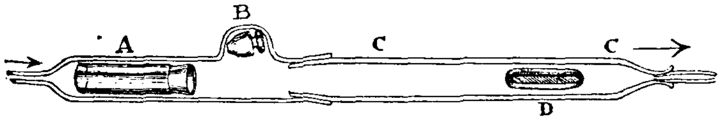

Fig. 2. Bottling Apparatus, Horizontal Section.

A = weighing bottle. B = stopper of bottle. CC = hard glass tube.
D = Platinum boat containing cobaltous bromide.

In the first place, nitrogen was prepared by passing air through strong ammonia water, and then over red hot copper. The nitrogen, after passing through several flasks of sulphuric acid, to remove the excess of ammonia, was conducted into column 1 (see Figure 3), containing beads soaked with silver nitrate, in order to free the gas from the possible admixture of sulphur compounds taken from the rubber connections which were used in the apparatus for making nitrogen. In the columns numbered 2 were beads drenched with strong sulphuric acid, which thoroughly dried the nitrogen. With stop-cock 12 open, the nitrogen passed over phosphoric anhydride in tube 11 directly into the bottling tube. With stop-cock 12 closed and 4 open, the nitrogen of necessity bubbled through bromine in the small flask 5; beyond this flask, if stop-cock 9 were open, the gases passed directly over phosphoric anhydride in 10 to the cobalt bromide; if stop-cock 9 were closed, the nitrogen and bromine together passed into the flask 6, containing hydrobromic acid and red phosphorus, thence into the U tube 7, containing beads moistened with hydrobromic acid and red phosphorus, thence over anhydrous calcic bromide in the tube 8 to remove the water taken from the hydrobromic acid, and finally over phosphoric anhydride in 10 to the bromide of cobalt. Dry air was prepared by passing a current of air through several columns of beads (OP in the figure) moistened with sulphuric acid, and then into the apparatus through the stop-cock 14. The pressure of the sulphuric acid in the bulb 3 prevented any air from backing up into the sulphuric acid columns delivering nitrogen. In order to prevent the slightest admixture of hydrobromic acid with the dry air used to wash out the apparatus at the conclusion of the operation, a slight excess of pressure was always maintained within the apparatus. This excess of pressure was so regulated as to cause a part of the pure

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* Richards and Parker, These Proceedings, XXXII. 59. Richards and Cushman (on Nickel), *ante*, p. 95.

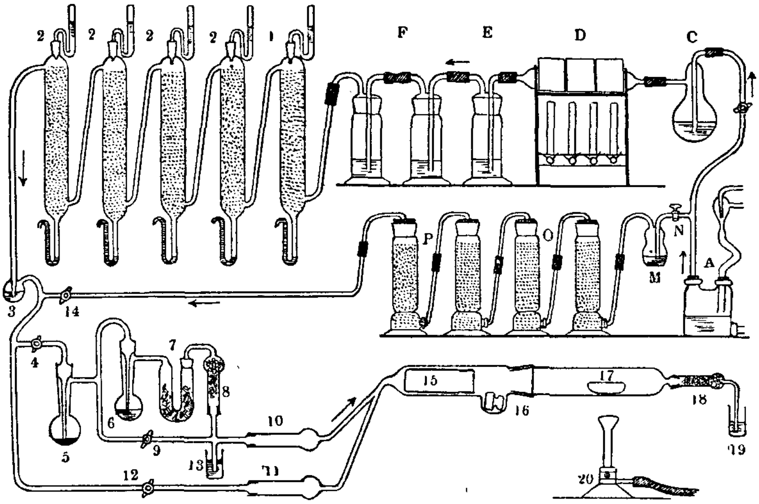

FIG. 3. APPARATUS FOR IGNITING COBALTOUS BROMIDE IN ANY DESIRED MIXTURE OF GASES.

The use of rubber was confined to the first part of this train, where it could do no harm. (A B C D E F and A M N O P).

air to go backwards through tube 10 (stop-cocks 4 and 9 being closed), and to bubble through the sulphuric acid kept in the vessel labelled 13. The tube and vessel served as a safety valve and pressure gauge throughout the whole operation. The ground joints were kept tight by means of syrupy phosphoric acid.

To the right hand end of the complex apparatus here described was fused the automatic bottling apparatus, as indicated in Figure 3. By means of this arrangement the cobaltous bromide could be thoroughly dried and enclosed in a suitable bottle for weighing without a moment's exposure to the moist air of the room. In one case, where a platinum boat containing several grams of the salt was reheated and rebottled after weighing, the loss in weight was found to be only 0.11 milligram, an amount not greater than the probable loss by sublimation at the high temperature (400°) employed in the ignition. Hence the apparatus evidently answers its purpose well.

The preliminary analyses were so much easier to make than those described in the preceding paper,— because of the ready solubility of the salt used and its invariable freedom from the oxide whose presence had caused trouble at first in the work upon nickel, — that only three were deemed necessary.

The method of procedure may be easily gathered from previous descriptions. The bromides of cobalt and silver were each weighed, as in the case of the nickel, and from the assumed molecular weight of argentic bromide 187.885 that of cobaltous bromide was calculated.

From the value for the atomic weight of cobalt obtained from this preliminary series, the approximate proportion of silver necessary for the complete decomposition of a given weight of cobaltous bromide was calculated; and in the succeeding analyses the proper amount of silver was weighed out in each case. After the silver had been dissolved with precautions to prevent loss during the process, and after the solutions of cobaltous bromide and argentic nitrate had been much diluted, the precipitation was effected in a roomy, glass-stoppered Erdenmeyer flask; and the mixture was very thoroughly shaken and allowed to stand. In three experiments, Nos. 4, 6, and 7, the precipitation was completed by titrating backward and forward with centinormal argentic nitrate and hydrobromic acid solution, until the precise point was found;* while in Nos. 8, 9, 11, 12, and 13 the nephelometer was used to determine the end-point.† Of course the work was done in yellow light or in darkness, and great care was taken to prevent the loss of any of the precipitate. The results of this determination of the amount of silver required to precipitate the bromine in cobaltous bromide are given in the table headed "Third Series" below. The "Second Series" of results was obtained by weighing the argentic bromide precipitated in the manner just described. Before filtering, a slight excess of argentic nitrate was

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* These Proceedings, XXVIII. 24; XXX. 384.

† Ibid., XXX. 385.

THE ATOMIC WEIGHT OF COBALT.

O = 16.000; Ag = 107.93.

First Series (Preliminary). 2 AgBr : $CoBr_2$.

Number of Analysis.	Sample of $CoBr_2$.	Weight of Cobaltous Bromide in Vacuum.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Cobalt.
1	I.	2.25295	3.86818	58.950
2	I.	2.88763	4.95732	58.975
3	I.	1.88806	3.24056	59.026
			Average	58.984

Second Series. 2 AgBr : $CoBr_2$.

Number of Analysis.	Sample of $CoBr_2$.	Weight of Cobaltous Bromide in Vacuum.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Cobalt.
4	I.	1.33564	2.29296	58.975
6	I.	2.58129	4.43095	58.998
7	I.	2.84382	4.88135	59.009
8	I.	1.83722	3.15368	59.000
9	I.	2.68584	4.61046	58.996
10	II.	3.18990	5.47607	58.982
11	II.	2.88914	4.95943	58.997
12	III.	2.32840	3.99706	58.987
13	IV.	1.91703	3.29053	59.010
			Average	58.995

THIRD SERIES. 2 Ag : $CoBr_2$.

Number of Analysis.	Sample of $CoBr_2$.	Weight of Cobaltous Bromide in Vacuum.	Weight of Silver in Vacuum.	Atomic Weight of Cobalt.
4	I.	1.33564	1.31702	59.002
6	I.	2.58129	2.54585	58.955
7	I.	2.84382	2.80449	58.977
8	I.	1.83722	1.81170	58.991
9	I.	2.68584	2.64879	58.969
11	II.	2.88914	2.84891	58.998
12	III.	2.32840	2.29593	59.003
13	IV.	1.91703	1.89033	58.999
		Average		58.987
		Average of Series II. and III. . .		58.991

added, and after long agitation the precipitate was collected as usual upon the Gooch crucible. The shreds of displaced asbestos were collected and weighed; and from the total was subtracted the small amount (if any) of argentic bromide resulting from hydrobromic acid added in titration. One experiment (No. 5), in which the cobaltous bromide contained a few visible chips of porcelain from the tube used in subliming, was rejected; and in one (No. 10) the weight of the silver was not determined.

As usual in cases of this sort, we may obtain a useful check upon the accuracy of these results by comparing the amount of silver required with the amount of argentic bromide formed. Thus, in all these experiments taken together 18.16302 grams of silver yielded 31.61642 grams of argentic bromide,— a ratio of 57.448 to 100.000. If we take only the last five experiments (8, 9, 11, 12, and 13) which were the most carefully made, the ratio becomes 57.446 : 100.000, while Stas's result is 57.445. The value of this comparison has been pointed out in the previous paper on nickel.

A still more important consideration is the identity of the results obtained from the various samples. The average of all the results of each of the four preparations is given below, — the first average comprehend-ing ten results, the second three, and the third, and fourth each two results.

Sample I.	58.987
Sample II.	58.992
Sample III.	58.995
Sample IV.	59.004

In this case, as in the case of nickel, a slight rise in the atomic weight is to be observed with the increasing purity of the materials. Although larger here than before, the rise cannot be considered greater than the probable experimental error,— especially since one or two of the individual results obtained from Sample I. were slightly greater than any obtained from Sample IV. We must therefore conclude that, if "gnomium" exists, it must have an atomic weight about equal to that of nickel and cobalt, and hence that the wide variations to be observed in the results of other experimenters cannot be considered a valid argument in favor of the late Professor Krüss's doubtful discovery.

According to the present investigation, then, the atomic weight of cobalt seems to be very close to 59. Upon comparing this result with the earlier ones of other experimenters, we see that this result is as much in accord with their general verdict as almost any other would be. In other words, the values are so various in magnitude that no satisfactory conclusion can be drawn from them. It is worth noticing that one of the results obtained by Thiele, under Professor Hempel's direction, agrees exactly with ours, however.

Our work thus has this outcome, at its present stage: —

If Oxygen = 16.000, Cobalt = 58.99.
If Oxygen = 15.88, Cobalt = 58.55.

Cambridge, Mass., June, 1897.

Proceedings of the American Academy of Arts and Sciences.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE CUPROSAMMONIUM BROMIDES AND THE CUPRAMMONIUM SULPHOCYANATES.

By Theodore William Richards and Benjamin Shores Merigold.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE CUPROSAMMONIUM BROMIDES AND THE CUPRAMMONIUM SULPHOCYANATES.

By Theodore William Richards and Benjamin Shores Merigold.

Presented November 10, 1897.

With regard to the possible compounds of cuprosammonium our knowledge is by no means complete. Many compounds which we should expect to find are not mentioned in chemical literature, and many which have been found are very imperfectly described. The present paper records the results of an investigation which had as its aim the filling up of some of the gaps in this direction; in particular we hoped to discover *cupros*ammonium double salts of the type $Cu_2(NH_3)_2BrC_2H_3O_2$, analogous to the *cupri*ammonium compounds which have recently been investigated here. While this latter hope has not yet found its fulfilment in fact, we have succeeded in preparing four new simple *cupros*-ammonium compounds: —

(1) $Cu_2(NH_3)_2Br_2$,
(2) $Cu_2(NH_3)_2(SCN)_2$,
(3) $Cu_2(NH_3)_6Br_2$,
(4) $Cu_2(NH_3)_{5(?)}(SCN)_2$;

and one *cupri*ammonium sulphocyanate: —

(5) $Cu(NH_3)_4(SCN)_2$.

1. Cuprosammonium Bromide, $Cu_2Br_2 . 2 NH_3$.

To prepare this compound, about ten grams of precipitated cuprous bromide were dissolved in the least possible amount of ammonic hydrate solution, and about twenty-five cubic centimeters of acetic acid were added. All operations were carried on with the help of a complex apparatus in an atmosphere of hydrogen, and the solution was evaporated spontaneously over sulphuric acid in a bell jar filled with hydrogen. After a day or two the bromide crystallized out in long colorless crystals.

Some difficulty was experienced in obtaining the substance dry in a pure state, as it begins to oxidize with the greatest readiness immediately upon removal from the mother liquor. The best results were obtained by the following method. The bell jar was so arranged that the mother liquor could be siphoned off, and successive portions of alcohol and ether could be introduced, the crystals all the time remaining in an atmosphere of hydrogen. After thus washing with alcohol and ether, some of the hydrogen was pumped out, and the last drops of ether evaporated in the partial vacuum. Prepared in this way, the substance was obtained in perfectly colorless long flat prisms. When thoroughly dry, it is stable and permanent at ordinary temperatures in the air. It is of course readily soluble in ammonic hydrate and in nitric acid, but deposits cuprous bromide upon treatment with other mineral acids, or with acetic acid. On exposure to moist air, and when placed in water, the substance oxidizes in a manner somewhat peculiar. The crystals first take on a bluish green tint, then gradually turn to a bright yellow, and finally change to a copper-red color. Owing to the fact that this change takes place only on the surface, the crystal within being unchanged, it was impossible to ascertain the nature of the yellow coating.

Cuprosammonium bromide was repeatedly obtained under a great variety of circumstances during many fruitless attempts to make the double salt $Cu_2(NH_3)_2BrC_2H_3O_2$. Between —10° and 25° the simple bromide appears to be by far the least soluble of the possible compounds obtainable from mixtures of cuprous copper, ammonia, bromine, and acetic acid.

In the analyses the bromine was determined as argentic bromide after dissolving the substance in ammonic hydrate, allowing the copper to oxidize by exposure to the air, and acidifying with nitric acid. Copper was determined electrolytically in a new portion after evaporating with nitric and sulphuric acids. The ammonia was distilled over potash.

Analyses of $Cu_2Br_2 . 2 NH_3$.

I. 0.2459 gram of substance gave, on electrolyzing, 0.0963 gram of copper.

II. 0.2059 gram of substance, distilled with caustic potash, required 13.04 cubic centimeters of decinormal acid solution for neutralization.

III. 0.3537 gram of substance, distilled with caustic potash, required 22.00 cubic centimeters of decinormal acid solution for neutralization.

IV. 0.3191 gram of substance yielded 0.3732 gram of argentic bromide.
V. 0.3045 gram of substance yielded 0.3576 gram of argentic bromide.

	Calculated for $Cu_2Br_2 . 2 NH_3$.	Found.					
		I.	II.	III.	IV.	V.	Average.
Copper	39.59	39.24	. . .	. . .	. . .	. . .	39.24
Ammonia . . .	10.63	. . .	10.78	10.61	. . .	. . .	10.69
Bromine . . .	49.78	. . .	. . .	. . .	49.78	49.97	49.88
	100.00						99.81

2. CUPROSAMMONIUM SULPHOCYANATE, $Cu_2(NH_3)_2(SCN)_2$.

In the first place, cuprous hydrate was prepared by adding an excess of a solution of sodic hydrate to cuprous chloride. The precipitated hydrate was washed once or twice and dissolved in the least possible amount of ammonic hydrate solution. On the addition of a concentrated solution of ammonic sulphocyanate, cuprosammonium sulphocyanate is precipitated as a white crystalline powder. Attempts to obtain larger crystals by using more dilute solutions were unsuccessful. The substance was washed with alcohol and ether, and dried rapidly by pressing between filter paper. Owing to the finely divided state in which the substance comes down, it is very difficult to dry it thoroughly and quickly in this fashion. It cannot be dried by exposure to the air, or over sulphuric acid, on account of the readiness with which it loses ammonia. Hence the analytical results are somewhat low on account of the presence of traces of moisture. The only remarkable property of this compound is its instability. Most of the other compounds of copper containing two molecules of ammonia are extremely stable, some of them retaining all their ammonia even at 100°. The cuprosammonium sulphocyanate, however, loses ammonia rapidly even at ordinary temperatures.

In many samples which had been allowed to stand for some time, the sulphocyanic acid also was found to be deficient. The two analyses given below are those of the two freshest preparations, and even they leave much to be desired in the way of accuracy. It is possible that the molecular rearrangement caused by the loss of the ammonia may induce an especial tendency toward oxidation, which, combined with the instability of cupric sulphocyanate,* might set free or decompose some sulphocyanic acid. Although, as has been said, the analyses are not exact, they are quite sufficiently accurate to prove the formula $Cu_2(NH_3)_2(SCN)_2$, for the respective atomic ratios found are 1.01 : 1.00 : 1.00, instead of the theoretical 1 : 1 : 1.

In the analysis the sulphocyanic acid was determined volumetrically according to the method of Volhard, after dissolving the substance in ammonic hydrate and allowing the copper to oxidize by exposure to the air.

Analyses of $Cu_2(NH_3)_2(SCN)_2$.

I. 0.2504 gram of substance gave, on electrolysis, 0.1133 gram of copper.

II. 0.2297 gram of substance required 16.09 cubic centimeters of a decinormal solution of silver nitrate for precipitation of the sulphocyanic acid.

III. 0.2645 gram of substance required 18.60 cubic centimeters of a decinormal solution of argentic nitrate for precipitation of the sulphocyanic acid.

IV. 0.2390 gram of substance required, after distilling with caustic potash, 16.57 cubic centimeters of a decinormal acid solution for neutralization.

V. 0.2822 gram of substance, after distilling with caustic potash, required 19.84 cubic centimeters of a decinormal acid solution for neutralization.

	Calculated for $Cu_2(NH_3)_2(SCN)_2$.	Found.					
		I.	II.	III.	IV.	V.	Average.
Copper	45.83	45.25	. . .	. . .	. . .	. . .	45.25
Ammonia . . .	12.29	. . .	. . .	. . .	11.83	12.00	11.91
Sulphocyanic acid	41.88	. . .	40.70	40.86	. . .	. . .	40.78
	100.00						97.94

Atomic ratios of copper to ammonia and to sulphocyanic acid found = 1.01 : 1.00 : 1.00.

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* Graham Otto, Michaelis, III. 892.

3. Tetrammon-Cuprosammonium Bromide, $Cu_2Br_2(NH_3)_{6(?)}$.

This compound is prepared by placing dry, finely powdered cuprous bromide in a bulb tube which is packed in ice, and passing in dry ammonia gas until the mass is saturated. The ammonia is absorbed with evolution of heat, the white cuprous bromide meanwhile turning dark brown and becoming hard and lumpy. In order to insure saturation, the mass must be removed from the tube occasionally and powdered. The saturated compound is a black powder, decomposed by water, soluble in ammonic hydrate and nitric acid. It is excessively unstable, giving off ammonia with the greatest ease. On this account the substance must be weighed while ice-cold, and hence also its analysis is far from satisfactory. The copper was determined in the residue from the ammonia determinations, in order to be sure of the proportion of copper to ammonia. The atomic proportions obtained in this way show that the formula given above is probably correct, although the analyses cannot be considered sufficiently definite to furnish conclusive proof. It is certain that the compound contains *at least* six molecules of ammonia.

Analyses of $Cu_2Br_2(NH_3)_6$.

I. 0.3276 gram of substance, distilled with caustic potash, required 50.30 cubic centimeters of a decinormal acid solution for neutralization.

II. 0.5746 gram of substance, distilled with caustic potash, required 87.03 cubic centimeters of a decinormal acid solution for neutralization.

III. 0.3276 gram of substance, — residue from I., — gave on electrolysis 0.1027 gram of copper.

	Calculated for $Cu_2Br_2 \cdot 6\,NH_3$.	Found. I.	 II.	 III.	 Average.
Copper	32.66	....	....	31.38	31.38
Ammonia	26.29	26.20	25.84	....	26.02

Atomic ratio of copper to ammonia found = 1 : 3.10.

4. Triammon-Cuprosammonium Sulphocyanate, $Cu_2(NH_3)_5(SCN)_2$.

This substance is prepared by a method similar to that used in the preparation of the saturated bromine compound described above. Dry ammonia gas is passed over dry powdered cuprous sulphocyanate, until the solid is saturated, the cuprous sulphocyanate being cooled by ice. The substance is a black powder, and possesses no remarkable properties.

It is very unstable, giving up ammonia rapidly on exposure to the air. The simplest method of determining the composition of the substance would naturally be to start with a known weight of cuprous sulphocyanate, pass in ammonia until saturated, and weigh again in sealed tube, no further analysis being necessary. This method is impossible, however, since, as in the case of the saturated bromine compound, the cuprous sulphocyanate hardens in absorbing the ammonia and has to be removed from the tube occasionally and powdered in order to insure saturation. As in the case of the bromine compound, too, the results of the analysis are unsatisfactory on account of the extreme instability of the compound. Copper was determined in the same sample with the ammonia in order to be sure of the proportion of copper to ammonia, and from the proportions so obtained it seems probable that the formula given is correct, in spite of the low results of the analyses. In any event, the atomic ratios $Cu_2 : (NH_3)_5$ must be assumed to represent the *minimum* amount of ammonia present in this compound.

Analyses of $Cu_2(SCN)_2(NH_3)_5$.

I. 0.5633 gram of substance, distilled with caustic potash, required 83.40 cubic centimeters of a decinormal acid solution for neutralization.

II. 0.4176 gram of substance, distilled with caustic potash, required 57.90 cubic centimeters of a decinormal acid solution for neutralization.

III. 0.4176 gram of substance gave, on electrolyzing, 0.1571 gram of copper.

	Calculated for $Cu_2(SCN)_2$, 5 NH_3.	Found.			
		I.	II.	III.	Average.
Copper	38.81	. . . .	. . . .	37.62	37.62
Ammonia	25.97	25.27	23.66	. . . .	24.47

Atomic ratio of copper to ammonia found = 2 : 5.05.

5. Diammon-Cupriammonium Sulphocyanate, $Cu(SCN)_2(NH_3)_4$.

In addition to the cuprosammonium compounds just described, we succeeded in preparing a new *cupri*ammonium sulphocyanate which contains two more molecules of ammonia than that discovered by Meitzendorf.* Our new substance was prepared by treating ten grams of cupric bromide with about fifteen cubic centimeters of strong ammonic hydroxide, and dissolving the resulting cupriammonium bromide by the addition of a little acetic acid. The addition to this mixture of a saturated solution of ammonic sulphocyanate caused the precipitation of a blue basic compound, which was dissolved by addition of ammonic hydrate. Soon deep blue crystals separated out from the solution. These were washed with alcohol and ether, and dried by pressing between filter paper. The washing with alcohol and ether must not be prolonged, otherwise the crystals lose their brilliant appearance and become covered with a coating of whitish basic salt. Prepared in this way, the compound occurs in very brilliant, deep blue crystals. On exposure to the air the crystals lose ammonia readily, and at the same time lose their brilliant lustre and become light blue in color. The salt is decomposed by water and by dilute acids; it is soluble in boiling concentrated hydrochloric acid, in cold strong nitric acid, and in ammonic hydroxide.

---

* Pogg. Annalen, LVI. 63, 92.

Analyses of $Cu(NH_3)_4(SCN)_2$.

I. 0.2540 gram of substance gave, on electrolysis, 0.0641 gram of copper.

II. 0.2064 gram of substance, distilled with caustic potash, required 33.71 cubic centimeters of a decinormal acid solution for neutralization.

III. 0.3454 gram of substance, distilled with caustic potash, required 55.20 cubic centimeters of a decinormal acid solution for neutralization.

IV. 0.1839 gram of substance required 14.71 cubic centimeters of a decinormal argentic nitrate solution to precipitate the sulphocyanic acid.

V. 0.3555 gram of substance required 28.38 cubic centimeters of decinormal argentic nitrate solution for precipitation of sulphocyanic acid.

	Calculated for $Cu(SCN)_2.4NH_3$	Found.					
		I.	II.	III.	IV.	V.	Average.
Copper	25.63	25.23	. . .	. . .	. . .	. . .	25.23
Ammonia . . .	27.52	. . .	27.81	27.26	. . .	. . .	27.54
Sulphocyanic acid	46.85	. . .	. . .	. . .	46.48	46.40	46.44
	100.00						99.21

The number of cuprammonium compounds, including the two classes *cupros-* and *cupri*-ammonium, seems to be almost unlimited. When a large amount of data has been accumulated, we shall be in a better position than we are at present to determine the constitution of these interesting bodies, and to explain their analogy to salts containing crystal water on the one hand, and their relations to the stable cobaltamine compounds on the other. For the present, the best that can be done is to multiply the available experimental evidence regarding them.

CAMBRIDGE, MASS., June, 1897.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE OXIDE OF DICHLORMETHOXYQUINONEDIBENZOYLMETHYLACETAL.

By C. Loring Jackson and H. A. Torrey.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE OXIDE OF DICHLORMETHOXYQUINONEDIBENZOYLMETHYLACETAL.*

By C. Loring Jackson and H. A. Torrey.

Presented May 12, 1897.

A paper on the acetals derived from substituted quinones published by H. S. Grindley and one of us in 1895, contained a description † of a substance made by the action of sulphuric acid on the dichlordimethoxyquinonedibenzoyldimethylacetal, which had the formula

$$C_6Cl_2(OCH_3)_2(OCOC_6H_5)_2O,$$

and which was called then the oxide of dichlordimethoxyhydroquinonedibenzoate; a name which the better knowledge of its constitution obtained from the work described in this paper makes it necessary for us to change to oxide of dichlormethoxyquinonedibenzoylmethylacetal.

As it seemed probable that the atom of oxygen in this substance was attached to two of the carbon atoms of the benzol ring, we decided to continue the study of it, and we describe the results of our work in this paper. In the preceding paper nothing had been done with this body beyond establishing its composition and that of the corresponding ethyl compound, and the preparation and partial study of a reduction product obtained from the ethyl oxide by the action of hydriodic acid.

In taking up again the study of the oxide the first point to be determined was whether the atom of oxygen is attached to one atom of carbon or to two. In the former case the substance must be either a ketone or a phenol. In writing the formula of this substance on the supposition that it is a ketone, it is necessary to assume such improbable intramolecular transformations that we felt inclined to reject the ketone formula on this ground alone; and this theoretical deduction was confirmed by the behavior of the substance. Hydroxylamine does not act on the body; but with phenylhydrazine products are obtained, to which we have devoted much attention with little result, because they are so unstable. They seem to resemble the isoamylamine compounds described later, and, if this is the case, tell against a ketone formula for the substance. This evidence, therefore, so far as it goes, is unfavorable to the ketone formula, but not conclusive against it. The action of a hot solution of sodic hydrate on our substance converted it into the sodium salt of chloranilic acid, and this result cannot be brought into harmony with a ketone formula, for in that case the sodic hydrate must have converted the ketone group C-O into a phenol group C-OH. The ketone attachment of the oxygen must, therefore, be rejected.

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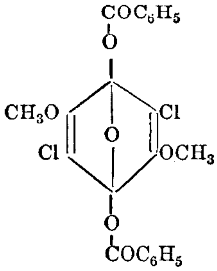
* The work described in this paper formed part of a thesis presented to the Faculty of Arts and Sciences of Harvard University for the Degree of Doctor of Philosophy, by H. A. Torrey.

† These Proceedings, XXX. 440.

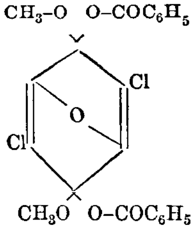
We have not succeeded in constructing any formula for our substance with the oxygen present in a hydroxyl group, as this would give seven substituting radicals to be arranged upon the benzol ring; and we may add that the existence of a hydroxyl group is inadmissible on experimental grounds, since cold sodic hydrate has no action upon the substance.

After we had thus proved that the oxygen is not attached to a single atom of carbon, a molecular weight determination was made, which showed that the body was derived from only one molecule of the substituted quinone. We next considered the different ways in which the atom of oxygen could be attached to two atoms of carbon, and this led to four possible formulas for the substance: —

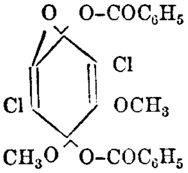
I.



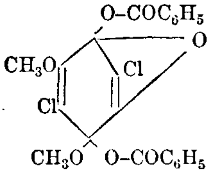
II.



III.



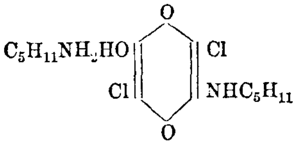
IV.



In Formulas I. and II. the attachment is to two atoms of carbon in the para position, which in I. are the quinone atoms of carbon, in II. those which are attached to the hydroxyls in chloranilic acid. Formula III. represents the oxygen attached to two atoms of carbon in the ortho position; and Formula IV. shows a meta attachment. Of the formulas we considered I. or II. the most probable, and devoted ourselves at first to the study of these.

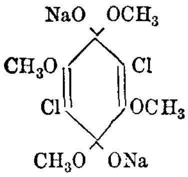
The conversion of the substance into chloranilic acid by the action of hot sodic hydrate can be easily explained by all four of these formulas, and therefore gives no aid in distinguishing between them.

Isoamylamine converts the oxide into the isoamylamine salt of oxydichlorisoamylamidoquinone, which has the following formula: —

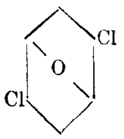


In forming this substance from a body having Formula I. it is necessary that the two methoxy groups should be acted on differently by the isoamylamine, since one of them is replaced by the isoamylamido group ($C_5H_{11}NH$), and the other converted into the phenol salt group ($C_5H_{11}NH_2HO$). Such an action would be highly improbable theoretically, as these two methoxy groups are symmetrically disposed in this formula; and it is proved to be impossible by our study of the action of isoamylamine on the similarly constituted dichlordimethoxyquinonedimethyldibenzoylacetal, $C_6Cl_2(OCH_3)_2(OCH_3)_2(OCOC_6H_5)_2$, which was converted by it into dichlordiisoamylamidoquinone, $C_6Cl_2(NHC_5H_{11})_2O_2$. Formula I., therefore, is not in harmony with these observations, and must be rejected. Formulas II., III., and IV. can be easily brought into harmony with the results of the experiments with isoamylamine, as will be shown later.

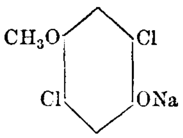
Sodic methylate converted the oxide into the sodium salt of the dichlordimethoxyquinonedimethylhemiacetal, which has the following formula: —



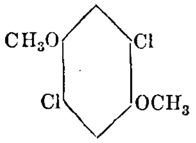
In deriving this compound from a substance having Formula II. the atom of oxygen must take up a molecule of sodic methylate, thus producing the intermediate body of these formulas :* —



Oxide.



Intermediate Body.

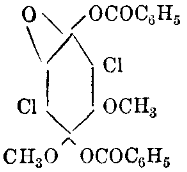


Hemiacetal.

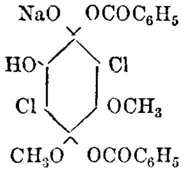
and then we must assume that the ONa of this body is converted into the OCH_3 of the hemiacetal by sodic methylate, an assumption which cannot be justified by any analogy, so that Formula II. must also be rejected.†

There remain only Formulas III. and IV., the unsymmetrical structure of which made us at first think them highly improbable; as a matter of fact, however, both of them explain in a satisfactory manner all the observations. This we will show only with Formula III., since Formula IV. would behave in a similar manner in every case.

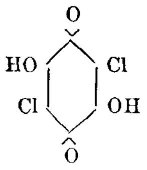
The conversion of the oxide into chloranilic acid by sodic hydrate would take place in three stages; first, the addition of one molecule of sodic hydrate to the atom of oxygen, thus: —



Oxide.



Intermediate Product.



Chloranilic Acid.

second, the saponification of the acetal groups to the quinone; and third, the saponification of the methoxy group to a hydroxyl.‡

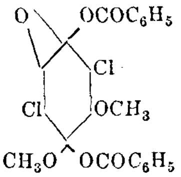
---

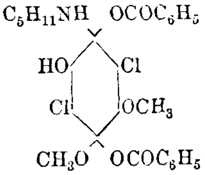
* In these formulas the radicals in the quinone positions have been left out for the sake of simplicity. They offer no difficulties, as will be shown later.

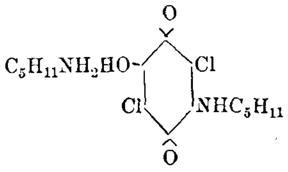
† It is perhaps worth while to state that the conversion of the hypothetical intermediate body into the hemiacetal could be brought about by splitting off sodic benzoate, thus forming a new oxide, which afterward might react with the sodic methylate; but, as this new oxide must have the conformation of either Formula III. or IV., it does not seem worth while to bring this strained hypothesis forward as a support for Formula II.

‡ That such methoxy groups on a quinone ring are saponified by sodic hydrate has been shown by the experiments of H. S. Grindley and one of us. (These Proceedings, XXX. 433.) In this respect they resemble those in picric ether or trinitrophloroglucine ether much more than those in anisol.

The formation of the isoamylamine salt of oxydichlorisoamylamidoquinone by the action of isoamylamine on the oxide would begin by the addition of one molecule of isoamylamine, forming the intermediate product, which would then be followed by the conversion of the acetal groups to the quinone, the replacement of the methoxy group by the isoamylamido group $C_5H_{11}NH$, and the addition of a molecule of isoamylamine to the hydroxyl. The two steps in this conversion which might be regarded as doubtful are the conversion of the acetal to the quinone by isoamylamine and the replacement of the methoxy by the isoamylamido group. Fortunately, we have been able to remove all doubt about both these steps by acting on the dichlordimethoxyquinonedimethyldibenzoylacetal,


O
OCOC6H5
Cl
Cl
OCH3
CH3O
OCOC6H5
Oxide.

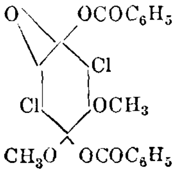

C5H11NH
OCOC6H5
HO
Cl
Cl
OCH3
CH3O
OCOC6H5
Intermediate Product.

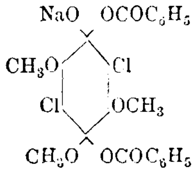

O
C5H11NH2HO
Cl
Cl
NHC5H11
O
Product.

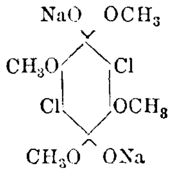
$$C_6Cl_2(CH_3O)_2(CH_3O)_2(OCOC_6H_5)_2,$$

with isoamylamine, when it was converted into dichlordiisoamylamidoquinone, $C_6Cl_2(C_5H_{11}NH)_2O_2$.

The formation of the sodium salt of the dimethylhemiacetal by the action of sodic methylate on the oxide is explained in a similar way: —


O
OCOC6H5
Cl
Cl
OCH3
CH3O
OCOC6H5
Oxide.


NaO
OCOC6H5
CH3O
Cl
Cl
OCH3
CH3O
OCOC6H5
Addition Product.


NaO
OCH3
CH3O
Cl
Cl
OCH3
CH3O
ONa
Hemiacetal.

the formation of the intermediate addition product being followed by conversion into a quinone, which then takes up two molecules of sodic methylate to form the hemiacetal.

The only other derivative of the oxide known is the reduction product* obtained by Grindley and one of us by the action of hydriodic acid. This substance gave upon analysis the formula $C_6Cl_2OC_2H_5OH(OCOC_6H_5)_2$, but has not yet been studied sufficiently to determine its constitution with certainty. We shall therefore content ourselves with saying that a substance with the formula given above could be easily derived from the oxide with the ortho attachment by the action of hydriodic acid.

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* These Proceedings, XXX. 442.

In the foregoing discussion of the formulas of the oxide, the arguments were based in large part upon the product obtained from it by the action of isoamylamine, and it is necessary, therefore, here to give our proofs of the constitution of this body. Its analysis led to the formula $C_6Cl_2(C_5H_{11}NH)(C_5H_{11}NH_2HO)O_2$, that is, an isoamylamine salt of a phenol, and this view was confirmed by the following observations: sodic hydrate set free isoamylamine from it; with hydrochloric acid a substance was obtained having the formula $C_6Cl_2(C_5H_{11}NH)HOO_2$, and melting at 188°; argentic nitrate converted it into $C_6Cl_2(C_5H_{11}NH)AgOO_2$, and we have also made the corresponding barium salt. That it was a quinone was shown by its dark color and its conversion into a colorless product by reduction. For the sake of comparison with this body we made the dichlordiisoamylamidoquinone, $C_6Cl_2(C_5H_{11}NH)_2O_2$, by the action of isoamylamine on chloranil, it melted at 224° to 225°; and also the isoamylamine salt of chloranilic acid, $C_6Cl_2(OHH_2NC_5H_{11})_2O_2$; both of which differed entirely in properties from the product made from the oxide.

The oxide when treated with diisoamylamine gave a compound corresponding to that from isoamylamine, $C_6Cl_2(C_5H_{11})_2N(C_5H_{11})_2NHHOO_2$, melting at 168° to 169°. With chloranil diisoamylamine gave

$$C_6Cl_2((C_5H_{11})_2N)_2O_2.$$

In looking for actions analogous to those just described, we are obliged to resort to the fat series, as no oxide similar to ours is known in the aromatic series, the nearest approach to it being cineol according to the formula ascribed to it by Brühl, in which, however, the oxygen spans the benzol ring in the para position. In the fat series ethylene oxide shows a structure similar to that of our oxide, as its atom of oxygen is attached to two adjacent atoms of carbon; and in its behavior with various reagents we find a marked similarity to the reactions of our oxide. Thus its conversion into glycol by the action of water corresponds to the formation of chloranilic acid by sodic hydrate, and with ammonia the ethylene oxide gives among other products an amino-alcohol, $HOCH_2CH_2NH_2$, analogous to the intermediate product which must be formed by the action of isoamylamine on our oxide. On the other hand we have not been able to find any case in which a fat oxide belonging to another than the *a* series shows these reactions, and this, so far as it goes, throws the balance in favor of adopting the ortho attachment of the oxygen (Formula III.) rather than the meta attachment (Formula IV.) in our oxide.

The decision between Formula III. (with the ortho attachment) and Formula IV. (with the meta attachment) could not be founded on any study of the derivatives of the oxide, as both formulas would give the same products when the oxygen bond was opened. We accordingly tried to solve the problem by the study of analogous substances, as follows: we exposed to the action of boiling sulphuric acid resorcine as an example of a substance with meta hydroxyls, and pyrocatechine (or some of its derivatives) as a substance with ortho hydroxyls, in the hope of obtaining an oxide similar to the one we have been studying, but in neither case was an oxide of this class formed. Resorcine under the action of boiling dilute sulphuric acid gave a body, which we recognized by its properties as resorcine ether formed by the union of two molecules of resorcine. The experiments with pyrocatechine and its derivatives, when the substance underwent any change, gave colored products, which were probably formed from a quinone. These experiments, therefore, threw no light upon the question.

From the discussion given above it appears that we cannot decide with certainty whether the oxygen in our oxide is in the ortho or meta position; we are of the opinion, however, that it has the ortho attachment, not only from the analogy between our oxide and ethylene oxide pointed out above, but also from the fact that the formation of anhydrides and similar couplings by two radicals in the meta position to each other are unknown, whereas these actions are among the most familiar characteristics of the ortho series.

We also describe tetrabromguaiacol, melting at 162° to 163°, and tribromveratrol, melting at 86° to 87°, which were made in connection with our work on the action of sulphuric acid on derivatives of pyrocatechine.

When we first undertook this work, we devoted a great deal of time to the preparation of mixed acetals like the dichlordiethoxyquinonedimethyldibenzoylacetal, as we hoped by the saponification of these substances to be able to determine which of the formulas of the oxide was correct; but these experiments led to no result, as the action of sodic methylate on dichlordiethoxyquinone, or of sodic ethylate on dichlordimethoxyquinone, produced mixtures from which the desired compounds could not be isolated. This is not surprising, as we found subsequently that the ethoxy groups could be replaced by methoxy groups, or the reverse, when one of our compounds was treated with the sodic alcoholate containing the radical, which was not already attached to its quinone ring.*

The acetyl acetals corresponding to the benzoyl acetals have also been made by us, and have the following melting points: —

$C_6Cl_2(OCH_3)_2(OCH_3)_2(OCOCH_3)_2$, melting point 177° to 178°;
$C_6Cl_2(OC_2H_5)_2(OC_2H_5)_2(OCOCH_3)_2$, melting point 120° to 121°.

We also describe some experiments on the action of sodic alcoholates on quinone itself and on chloranil, which led to substances probably similar to the colored compounds obtained from nitro aromatic bodies by the action of sodic alcoholates by Lobry de Bruyn,† Victor Meyer,‡ and Ittner and one of us.§ These experiments were abandoned after some progress had been made on account of the work of Astre ‖ in the same field, and are described here only because they cannot be brought into harmony with the theory advanced by Astre to account for these substances. The discussion of this question will be found in the experimental part.

We also observed that an alkaline solution of sodic chloranilate was converted into iodoform by treatment with iodine.

EXPERIMENTAL PART.

Preparation of the Oxide of Dichlormethoxyquinonedibenzoylmethylacetal, $C_6Cl_2OCH_3O(CO_2C_6H_5)_2OCH_3$.

This preparation was carried on essentially in the manner described by Grindley and one of us in a previous paper,¶ but we think it best to describe the process again here, as in that paper it is not given continuously, but scattered through different paragraphs, and also because we have introduced a few improvements in the details.

To convert chloranil into dichlordiphenoxyquinone fifty grams of chloranil, previously converted to a fine powder by reduction to tetrachlorhydroquinone by sulphurous acid followed by oxidation with nitric acid,** were treated with a strong aqueous solution of potassic phenylate made from fifty grams of phenol and twenty-five grams of potassic hydrate. The product was washed thoroughly with water, then with alcohol, and finally with benzol or ether. It was not recrystallized.

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* Compare Gattermann and Ritschke, Ber. d. chem. Ges., XXIII. 1738 (1890).

† Rec. Trav. Chim. Pays Bas, XIV. 89.

‡ Ber. d. chem. Ges., XXVII. 3153.

§ Am. Chem. Journ., XIX. 199.

‖ C. R., CXXI. 326, 530.

¶ These Proceedings, XXX. 423.

** This preliminary treatment is essential to the success of the process. We have not succeeded in getting a sufficiently fine powder by mechanical pulverization.

The dichlordiphenoxyquinone was then converted into the dichlordimethoxydimethylhemiacetal by adding twenty grams of it in small portions at a time with constant agitation to the sodic methylate made from five grams of metallic sodium and 120 c. c. of methyl alcohol. It was found best to carry on this reaction in a flask. The mixture was then warmed on the water bath, and afterward allowed to stand for a short time to permit the separation of the sodium salt of the hemiacetal, which was sometimes hastened by the addition of a little ether. The salt collected on a filter was washed with ether and with a very little alcohol, or better a mixture of alcohol and ether.

The dibenzoylacetal was next made by treating twenty-five grams of the dry salt suspended in a small quantity of methyl alcohol with twenty-two grams of benzoylchloride. The reaction was completed by warming the mixture for a short time on the water bath. The product usually contained, in addition to the colorless dibenzoylacetal, a red substance, probably dichlordimethoxyquinone, which was most easily removed by treatment with warm sodic hydrate, as this reagent converted the red substance into sodic chloranilate, but did not act on the acetal. The chloranilate was then washed out with hot water, leaving the acetal pure enough for our purposes.

The dry acetal was next saponified by heating it for fifteen or twenty minutes in a flask with a return condenser with sulphuric acid of specific gravity 1.44. The contents of the flask were then allowed to cool, and after the addition of a little water the solid product was filtered out, and washed with hot water to remove the chloranilic acid always formed in the reaction. The white oxide left was then purified by one or two recrystallizations from chloroform and alcohol. The yield of oxide was a little under 80 per cent of the amount which should be obtained from the acetal.

The processes which are carried on in this preparation are represented by the following reactions: —

$$C_6Cl_4O_2 + 2\ NaOC_6H_5 = C_6Cl_2(OC_6H_5)_2O_2 + 2\ NaCl.$$

$$C_6Cl_2(OC_6H_5)_2O_2 + 4\ NaOCH_3 = C_6Cl_2(OCH_3)_2(ONa)_2(OCH_3)_2 \\ + 2\ NaOC_6H_5.$$

$$C_6Cl_2(OCH_3)_2(ONa)_2(OCH_3)_2 + 2\ C_6H_5COCl = \\ 2\ NaCl + C_6Cl_2(OCH_3)_2(OCOC_6H_5)_2(OCH_3)_2.$$

$$C_6Cl_2(OCH_3)_2(OCOC_6H_3)_2(OCH_3)_2 + H_2O = \\ C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3 + 2\ CH_3OH.$$

Determination of the Molecular Weight of the Oxide.

This determination was made to find out whether the oxide was derived from one or more molecules of the benzoylacetal. The boiling point method of Beckmann was used with benzol as the solvent, and the following results were obtained:—

Solvent.	Substance.	Δ	M
17.08	0.4315	0.138°	489
17.05	0.6761	0.228°	465
17.02	0.9787	0.328°	468
		Mean	474

The temperature error did not exceed 3° in the last decimal place.

Calculated Molecular weight for $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.	Found. Mean.
463	474

These results show that the oxygen atom does not bind together two benzol rings.

Action of Sodic Hydrate on the Oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.

The oxide did not dissolve in a cold solution of sodic hydrate, but when the two substances were allowed to stand together for twenty hours, it was found that a small quantity of sodic chloranilate had separated out.

If, on the other hand, the oxide was boiled with sodic hydrate, it was decomposed rapidly even when a dilute solution was used. 1.5 grams of the oxide were boiled for half an hour with a solution of 5 grams of sodic hydrate in 60 c. c. of water; at the end of this time the oxide had disappeared completely, and the liquid had taken on a dark purple color. It was filtered while still hot, and the filtrate on cooling deposited crystals, which looked like sodic chloranilate. To determine their composition they were collected on a filter, and, after washing with alcohol and a little water, recrystallized from hot water. The crystals were then dried over sulphuric acid, and finally at 110°–120°, when an analysis gave the following result:—

0.1707 gram of the salt gave 0.0949 gram of sodic sulphate.

	Calculated for $C_6Cl_2(ONa)_2O_2$.	Found.
Sodium	18.18	18.02

The product therefore was sodic chloranilate.

Action of Sodic Methylate on the Methyl Oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.

One gram of the oxide was added to a solution of sodic methylate made by the action of 0.2 gram of metallic sodium on 10 c. c. of methyl alcohol. After heating the mixture for a short time on the water bath the liquid became slightly yellow, and the oxide went into solution, but soon after a white substance was deposited, the quantity of which increased as the liquid cooled; at the same time the odor of benzoic methylester was observed. The product of the reaction was allowed to stand at ordinary temperatures for half an hour, after which the white precipitate was collected on a filter, and washed at first with methyl alcohol, in which it is only slightly soluble, and finally with ether. The washed precipitate was then dissolved in water, and the solution, after it had been filtered, acidified with dilute hydrochloric acid. The white flocculent precipitate formed by the acid was washed thoroughly with water, alcohol, and ether; and next redissolved in sodic hydrate, filtered, and reprecipitated with dilute hydrochloric acid. These solutions and reprecipitations were repeated several times until the precipitate was perfectly white.

The amorphous white substance thus obtained was very similar in appearance to a hemiacetal. It was dried and analyzed with the following result: —

0.1368 gram of the substance gave by the method of Carius 0.1300 gram of argentic chloride.

	Calculated for $C_6Cl_2(OCH_3)_2(OH)_2(OCH_3)_2$.	Found.
Chlorine	23.59	23.49

This analysis indicates that the substance is the dichlordimethoxyquinonedimethylhemiacetal, and this view of its composition is confirmed by the following experiment. A small quantity of the substance was heated with dilute hydrochloric acid, when a red crystalline body was obtained melting in the crude state at 140°, after recrystallization at 141°. This must therefore have been the dichlordimethoxyquinone whose melting point is 141°–142°.

The hemiacetal could be formed from the oxide by the following reactions: —

$$C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3 + NaOCH_3 =$$
$$C_6Cl_2(OCH_3)_2ONa(OCOC_6H_5)_2OCH_3 =$$
$$C_6H_5COONa + C_6H_5COOCH_3 + C_6Cl_2(OCH_3)_2O_2.$$

An odor of benzoic methylester was observed, as already stated.

$$C_6Cl_2(OCH_3)_2O_2 + 2\ NaOCH_3 = C_6Cl_2(OCH_3)_2(ONa)_2(OCH_3)_2.$$

Action of Sodic Methylate on the Ethyl Oxide $C_6Cl_2(OC_2H_5)O(OCOC_6H_5)_2OC_2H_5$.

One gram of the ethyl oxide was added to a solution of sodic methylate made by the action of 0.2 gram of sodium on 12 c. c. of methyl alcohol. The oxide went into solution at once, but after the solution had been heated on the steam bath for a short time a white precipitate was thrown down, the amount of which was increased by the addition of ether. After purification by alternate precipitation by hydrochloric acid, and solution in sodic hydrate, as described in the preceding section, the substance was dried in a desiccator, and analyzed with the following result: —

0.1527 gram of the free hemiacetal gave by the method of Carius 0.1456 gram of argentic chloride.

	Calculated for $C_6Cl_2(OCH_3)_2(OH)_2(OCH_3)_2$.	Found.
Chlorine	23.59	23.58

As the mixed ethyl methylhemiacetal, which would be expected here, contains 21.58 per cent of chlorine, there can be no doubt that the product was the dimethylhemiacetal; and this view was confirmed by the following experiment. A small quantity of the substance was heated with dilute hydrochloric acid, when a red solid was formed which melted at 140°, and therefore was the dichlordimethoxyquinone. From these observations it follows that the behavior of the ethyl oxide with sodic methylate is the same as that of the methyl oxide, except that, in addition to the formation of the hemiacetal, the ethoxy groups have been replaced by methoxy groups.

After the work just described had shown that ethoxy groups in the ethyl oxide could be replaced by methoxy groups under the influence of sodic methylate, the following experiment was tried to see whether a similar change could be produced with the dichlordiethoxyquinone: 0.7 gram of this substance were treated with a solution of the sodic methylate made from 0.2 gram of sodium and 5 c. c. of methyl alcohol; the hemiacetal formed was decomposed with dilute hydrochloric acid, and the red quinone obtained recrystallized from alcohol, and then from benzol, when it melted at 139°, showing that it was dichlordimethoxyquinone, and therefore that the methoxy groups had replaced the ethoxy groups in this case also, as was to be expected.

We next tried an experiment to see whether the reverse change could be brought about. One gram of the methyl oxide,

$$C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3,$$

was treated with a solution of sodic ethylate, and the hemiacetal formed decomposed with hydrochloric acid, when the crude quinone thus obtained melted at 100°–105°, and recrystallization did not raise the melting point above 105°; it is, therefore, dichlordiethoxyquinone, which melts at 104°–105°, and the ethoxy group has replaced the methoxy group. These experiments make it probable that any alcohol radical can be replaced by any other in these substituted quinones, if the substance is treated with the proper sodic alcoholate,* and therefore that the isolation of mixed hemiacetals containing one radical on the ring and another in the acetal part of the molecule would be a matter of great difficulty. These experiments were in fact undertaken to explain the failure of our work on such mixed hemiacetals and acetals, which we had tried to prepare, because we hoped the conversion of them into the corresponding oxides would throw some light on the constitution of these latter bodies. Our attempts to make the dimethoxyquinonediethyldibenzoylacetal led to the diethoxydiethyl body as the principal product, but probably a small quantity of the mixed acetal was also formed, as the crude product began to melt at 130°, and it was only after many crystallizations that the pure diethoxydiethylacetal melting at 170° could be obtained.

Action of Isoamylamine on the Oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.

Three grams of the oxide were dissolved in hot benzol, and 4.5 grams of free isoamylamine were added with constant stirring. A reaction took place at once with the formation of a yellow precipitate so abundant that the contents of the beaker became almost solid. As this yellow substance is very unstable, we devoted our attention at first to the product of its decomposition, which was more easily obtained and purified. To bring about the decomposition the mixture was heated gently, when the yellow color changed to a purplish red, and the greater part of the solid went into solution, but was deposited as the benzol cooled. The purplish red solid thus obtained was washed with benzol, and then with water, after which it was purified by recrystallization from hot benzol, to which a very little methylalcohol had been added. It was then dried at 100° and analyzed with the following results: —

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* Replacements similar to these have been observed with other classes of bodies by Friedel and Crafts, Ann. Chem., CXXXIII. 208; Israel, Ibid., CCXXXI. 220; Isbert, Ibid., CCXXXIV. 160; Peters, Ibid., CCLVII. 353; Purdie, Ber. d. chem. Ges., XX. 1554; Bertoni, Gaz. Chim., XII. 435, XV. 361; and Gattermann and Ritschke, Ber. d. chem. Ges., XXIII. 1738 (1890).

I. 0.1089 gram of the substance gave by combustion 0.2085 gram of carbonic dioxide and 0.0715 gram of water.

II. 0.1147 gram of the substance gave by the method of Carius 0.0931 gram of argentic chloride.

III. 0.1216 gram of the substance gave 0.0969 gram of argentic chloride.

	Calculated for $C_6Cl_2C_5H_{11}NHONH_3C_5H_{11}O_2$.	Found.		
		I.	II.	III.
Carbon	52.60	52.22		
Hydrogen	7.19	7.29		
Chlorine	19.45		20.06	19.71

These results show that the substance is the isoamylamine salt of the dichlorisoamylamidoxyquinone. The formation of such a body from the oxide can be explained by the following reactions.* In the first place, the addition of one molecule of isoamylamine to the atom of oxygen forming $C_6Cl_2OCH_3OH(C_5H_{11}NH)(OCOC_6H_5)_2OCH_3$; next, the replacement of the methoxy group by an isoamylamido group, and the addition of a molecule of isoamylamine to the hydroxyl giving a complex substance, which must have had this formula: —

$$C_6Cl_2(C_5H_{11}NH)(OHNH_2C_5H_{11})C_5H_{11}NH(OCOC_6H_5)_2OCH_3.$$

This would finally be decomposed by the removal of benzisoamylamide and benzoic methylester leaving the body analyzed

$$C_6Cl_2C_5H_{11}NHOHC_5H_{11}NH_2O_2.$$

That the methoxy group can be replaced by the isoamylamido radical and the substituted acetal saponified to the quinone under these conditions will be proved by some experiments described later in this paper.

Properties of the Isoamylamine Salt of Dichlorisoamylamidoxyquinone, $C_6Cl_2(C_5H_{11}NH)(ONH_3C_5H_{11})O_2$. — This substance, when crystallized from a mixture of benzol and methyl alcohol, appears in purplish red needles, which, when examined with the microscope, are seen to be long, very slender spindle-shaped plates or flattened needles of a pale purple color. When heated it decomposes into the free phenol melting at its usual temperature, 188°, and isoamylamine, which could be seen coating the upper parts of the melting tube, and was recognized by its odor. It is easily soluble in methyl or ethyl alcohol; soluble in acetone, or acetate of ethyl; slightly soluble in cold benzol, or chloroform, more soluble in either of these solvents when hot; insoluble in ether, ligroin, carbonic disulphide, or water; glacial acetic acid dissolves it, but nothing is precipitated from this solution by the addition of water. All of its solutions show a purple color. The best solvent for it is a mixture of benzol and a little methyl alcohol. Dilute hydrochloric acid, or nitric acid, converts it into a black powder. If a strong acid is used, a red solution is formed, from which water precipitates the black substance. The most convenient way of obtaining this black body is by adding dilute hydrochloric acid to an alcoholic solution of the salt, when it falls as a precipitate. It is the free phenol $C_6Cl_2(C_5H_{11}NH)OHO_2$, which is described later in this paper. An aqueous solution of sodic hydrate does not dissolve the substance, but, if the alkali is added to an alcoholic solution of the salt, a light colored compound is precipitated, and at the same time the odor of an amine is observed; heavy white fumes are produced, when hydrochloric acid vapors are brought near the vessel containing this mixture. The precipitate is, therefore, probably the sodium salt, but it was not thought worth while to study it. Baric chloride gives a violet precipitate, argentic nitrate a red gelatinous precipitate, when added to an alcoholic solution of the salt. These precipitates were more carefully studied in order to characterize the substance more thoroughly.

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* These reactions are arranged in the order which we think will be most easily understood. We do not mean to imply that they took place in this order; in fact, our work on the yellow product seems to indicate that they did not.

Silver Salt of Dichlorisoamylamidoxyquinone,
$C_6Cl_2(C_5H_{11}NH)OAgO_2, 2\,H_2O$.

This salt was prepared by adding to a dilute alcoholic solution of the isoamylamine salt an aqueous solution of argentic nitrate in excess. After stirring the solution for some time a mass of olive-gray needles separated, which were collected on a filter, washed very thoroughly with water, and with a mixture of alcohol and water, sucked dry on the filter pump, and then dried in a desiccator over sulphuric acid to a constant weight. The analysis of the salt gave the following results: —

0.1387 gram of the salt dried in a desiccator lost 0.0124 gram of water when heated to 105°–110°.

	Calculated for $C_6Cl_2(C_5H_{11}NH)OAgO_2, 2\,H_2O$.	Found.
Water	8.58	8.94

The amount of silver in the salt dried at 105°–110° was determined by heating it in a sealed tube with nitric acid (specific gravity 1.5) and weighing the argentic chloride formed.

I. 0.1223 gram of the substance gave 0.0459 gram of argentic chloride.
II. 0.1866 gram of the substance gave by the method of Carius (with an excess of argentic nitrate) 0.1425 gram of argentic chloride.

	Calculated for $C_6Cl_2(C_5H_{11}NH)OAgO_2$.	Found.	
		I.	II.
Silver	28.05	28.18	
Chlorine	18.44		18.88

Properties of the Silver Salt. — If in making this salt the argentic nitrate is added slowly to a cold dilute solution of the isoamylamine salt, and the separation takes place slowly, the salt is obtained in olive-gray needles, which contain two molecules of water of crystallization, as shown by the analysis given above. These needles, when heated to 110°, lose the water of crystallization, and turn red. If, on the other hand, the solution of argentic nitrate is added to a warm concentrated solution of the isoamylamine salt, a red gelatinous precipitate is obtained, which looks very much like currant jelly, and to judge from its color consists of the anhydrous salt. The red gelatinous mass showed a tendency to pass over into the gray crystalline form; and the red amorphous body could be obtained from the gray needles by dissolving them in a hot mixture of alcohol and water and cooling rapidly. The crystallized salt is very slightly soluble in cold water, more so in hot; slightly soluble in alcohol. The red amorphous form is insoluble in either water or alcohol.

The colorless filtrate from the olive-gray crystals obtained in the preparation of the silver salt was treated with sodic hydrate, when a strong smell of isoamylamine was observed, showing that the atom of silver had replaced the molecule of isoamylamine in the original salt, as was to be expected.

Barium Salt of Dichlorisoamylamidoxyquinone,
$[C_6Cl_2(C_5H_{11}NH)OO_2]_2Ba \, . \, 2\,H_2O$.

This salt was prepared by adding a dilute solution of baric chloride to the isoamylamine salt dissolved in cold alcohol. The purplish precipitate was collected on a filter, and washed first with alcohol, and afterward with water, until the wash water gave no test for a chloride. It was then dried *in vacuo* over calcic chloride, and analyzed with the following results: —

0.2063 gram of the salt dried *in vacuo* lost 0.0100 gram of water when heated to 110°.

	Calculated for $[C_6Cl_2(C_5H_{11}NH)OO_2]_2Ba \cdot 2\,H_2O$.	Found.
Water	4.95	4.85

0.1958 gram of the salt dried at 110° gave 0.0641 gram of baric sulphate.

	Calculated for $[C_6Cl_2(C_5H_{11}NH)OO_2]_2Ba$.	Found.
Barium	19.83	19.25

Properties of the Barium Salt. — It consists of crystalline plates of a violet color, which are slightly soluble in cold water, more soluble in hot, but insoluble in alcohol. A dilute solution of the salt gives the black free oxyquinone on addition of hydrochloric acid.

Dichlorisoamylamidoxyquinone, $C_6Cl_2(C_5H_{11}NH)OHO_2$.

This substance is formed whenever one of its salts is treated with dilute hydrochloric acid. It was prepared for analysis by adding dilute hydrochloric acid to a solution of the purple isoamylamine salt in warm alcohol; the black precipitate thus obtained was washed thoroughly with water, and then crystallized from hot benzol, until it showed the constant melting point 188°, when it was dried at 100°, and analyzed with the following results: —

0.1756 gram of the substance gave by the method of Carius 0.1832 gram of argentic chloride.

	Calculated for $C_6Cl_2(C_5H_{11}NH)OHO_2$.	Found.
Chlorine	25.54	25.80

Properties of Dichlorisoamylamidoxyquinone. — The substance forms bronze black flattened needles, or long plates. When crystallized from hot alcohol and examined with the microscope, rhombic plates are sometimes observed, which are more usually united into short and broad plates looking like an hour glass; these crystals have a brownish yellow color, but look black when in thicker layers, as, for instance, when two plates overlap, the portions in contact with each other look black, while the other parts of both plates are brownish yellow, thus giving a very characteristic effect. As the crystallization continues, the hour glass forms develop into the long plates mentioned at first. It melts at 188°; it is soluble in methyl or ethyl alcohol, benzol, chloroform, ether, or acetone; slightly soluble in ligroin; very slightly soluble in carbonic disulphide. Benzol is the best solvent for it. Its solutions show a purple color. Strong sulphuric acid dissolves it with a purple color, but the original substance is precipitated from this solution by dilution with water. Sodic hydrate dissolves it, forming a purple solution, from which acids throw down the unaltered substance. The properties of the substance, therefore, confirm the inference drawn from its preparation and analysis, that this is the free oxyquinone.

Yellow Product of the Action of Isoamylamine on the Oxide.

In the description of the action of isoamylamine on the oxide it was stated that a yellow substance was formed at first, which was converted by heating the mixture into the purple isoamylamine salt of the dichlorisoamylamidoxyquinone. It would have been interesting to determine the composition of this intermediate product between the salt and the oxide, but unfortunately it was so unstable, and its properties rendered its purification so doubtful, that we can make no certain statement in regard to it.

It was prepared by dissolving 0.5 gram of the oxide

$$C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$$

in a large quantity of benzol, and adding with continual stirring 0.6 gram of isoamylamine. The solution immediately turned yellow, and after standing for a minute or two suddenly began to coagulate, and finally solidified entirely into a yellow gelatinous mass with a slight greenish fluorescence. It was washed on a filter with benzol, until the filtrate, which was red at first, became colorless, and was then dried on a porous plate; but, as it darkened somewhat, it was washed again with chloroform and alcohol, until it was yellow throughout. After drying *in vacuo* an analysis was made, which gave 16.66 per cent of chlorine. This is not far removed from 15.93, the percentage of chlorine in the not improbable intermediate compound

$$C_6Cl_2CH_3O(OHNH_2C_5H_{11})O(OCOC_6H_5)OCH_3,$$

in which one of the acetal groups has been saponified to a quinone oxygen. We did not attempt to get more analyses of this substance, because, owing to its instability and amorphous character, we did not feel that much confidence could be placed in them, and therefore preferred to devote our time to work which had a more immediate bearing on the nature of the oxide, and which also promised to give more trustworthy results.

Action of Isoamylamine on Chloranil Dichlordiisoamylamidoquinone,

$$C_6Cl_2(C_5H_{11}NH)_2O_2.$$

The work described in this and the two following sections of the paper was undertaken to obtain bodies closely related to our isoamylamine salt of dichlorisoamylamidoxyquinone, the study of which might throw some light on the formation of that body.

Two grams of chloranil were dissolved in hot benzol, and heated with two grams of isoamylamine with constant stirring. At first a green coloration was noticed similar to that obtained by the action of sodic alcoholates on chloranil, but on longer heating of the mixture this green color gave place to a purple, and on cooling beautiful purple plates separated from the solution. The substance was washed thoroughly with alcohol to remove a white impurity, probably the chloride of isoamylamine, which had separated with it, and then recrystallized from benzol until it showed the constant melting point 224°–225°, when it was dried at 100°, and analyzed with the following result: —

0.1786 gram of the substance gave by the method of Carius 0.1500 gram of argentic chloride.

	Calculated for $C_6Cl_2(C_5H_{11}NH)_2O_2$.	Found.
Chlorine	20.46	20.76

Properties of Dichlordiisoamylamidoquinone. — The substance crystallizes in long plates or flattened needles terminated by a single plane at a not very oblique angle to the sides. The color is a dark red, and the crystals often show a marked purple iridescence, when separating from solution. It melts at 224°–225°. It is slightly soluble in cold benzol, more freely in hot; almost insoluble in alcohol; insoluble in water. The best solvent for it is benzol. Strong hydrochloric acid has no apparent action on it; strong sulphuric acid dissolves it, but the original red body is precipitated on the addition of water.

Action of Isoamylamine on Dichlordimethoxyquinonedimethyldibenzoylacetal.

To study this action 0.7 gram of the acetal were dissolved in hot benzol, mixed with 1.1 grams of isoamylamine, and the mixture heated to boiling on the steam bath. On cooling crystals were deposited exactly similar in appearance to those obtained by acting on chloranil with isoamylamine. After crystallization from benzol they melted at 224°–225°, and therefore were the dichlordiisoamylamidoquinone, with which the substance also agreed in its other properties. Dichlordimethoxyquinone also gives this same product, when treated with isoamylamine.

These experiments show that the methoxy radical in these substituted quinones can be replaced by the isoamylamido group, when the quinone is heated with isoamylamine, and also that isoamylamine is able to convert a benzoylmethylacetal into the corresponding quinone, two points which are of great importance in interpreting the transformations of the oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$ under the influence of isoamylamine.

Isoamylamine Salt of Chloranilic Acid, $C_6Cl_2(OHNH_2C_5H_{11})_2O_2$.

This salt was made by dissolving a small quantity of chloranilic acid in warm alcohol, and adding a slight excess of isoamylamine; the salt appeared as an abundant purplish red precipitate, which was purified by washing it with benzol, alcohol, and water. It was dried at 110°, and gave the following results on analysis: —

I. 0.1307 gram of the salt gave by the method of Carius 0.0992 gram of argentic chloride.

II. 0.2208 gram of the salt gave 0.1672 gram of argentic chloride.

	Calculated for $C_6Cl_2(OHNH_2C_5H_{11})_2O_2$.	Found. I.	Found. II.
Chlorine	18.54	18.77	18.72

Properties of the Isoamylamine Chloranilate. — It is a purplish red crystalline substance; slightly soluble in methyl or ethyl alcohol; also somewhat soluble in glacial acetic acid, but decomposed by it; essentially insoluble in benzol, ether, chloroform, acetone, ligroin, carbonic disulphide, or ethylacetate. Hydrochloric acid decomposes the salt, giving a solution of chloranilic acid, which was recognized by the purple color of its aqueous solution, and the formation from this solution of the characteristic red silver salt.

Action of Diisoamylamine on the Oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.

After the study of the action of isoamylamine on the oxide, which has been just described, it seemed of interest to determine whether a secondary amine would act like a primary amine on the oxide, and accordingly we took up this work with diisoamylamine.

When to one gram of the oxide dissolved in hot benzol 2.5 grams of diisoamylamine were added, the solution turned yellow immediately, and this color finally gave place to red. On cooling no solid separated, but after evaporating off part of the solvent a reddish compound appeared. To obtain this in quantity the greater part of the benzol was evaporated off on the steam bath, and the rest was allowed to pass off spontaneously. The red solid left was washed thoroughly with water, and purified by crystallization, at first from a mixture of alcohol and water, and finally from ligroin, until it showed the constant melting point 168°–169°, when it was dried at 100°, and analyzed with the following result: —

0.1245 gram of the substance gave by the method of Carius 0.0714 gram of argentic chloride.

	Calculated for $C_6Cl_2(C_5H_{11})_2N(OHNH(C_5H_{11})_2)O_2$.	Found.
Chlorine	14.06	14.17

Properties of the Diisoamylamine Salt of the Dichlordiisoamylamidoxyquinone. — It separates from hot ligroin in reddish brown crystals, which melt at 168°–169°. It is very soluble in acetone, benzol, or chloroform; soluble in cold alcohol, easily soluble in hot; somewhat soluble in cold ligroin, more freely in hot. The addition of an acid to the alcoholic solution sets free the oxyquinone, which usually is precipitated as an oil. Plumbic acetate, when added to the alcoholic solution, gave a greenish precipitate.

As the analysis and properties of this substance showed that diisoamylamine had acted on the oxide in precisely the same way as the isoamylamine, we decided not to pursue this line of work further.

Action of Diisoamylamine on Chloranil.

A small quantity of chloranil dissolved in hot benzol was treated with an excess of diisoamylamine. A green coloration was first noticed, which changed to brown in a short time, while a white crystalline substance was precipitated, which was recognized as the chloride of diisoamylamine by its properties. After the solution had been evaporated to a slight extent on the steam bath, the insoluble diisoamylamine salt was filtered out, and the filtrate mixed with its own volume of alcohol allowed to evaporate spontaneously. After several hours beautiful purplish black needles separated from the liquid, which were washed with alcohol and finally recrystallized from alcohol to purify them. After drying *in vacuo* it gave the following result on analysis: —

0.0971 gram of the substance gave by the method of Carius 0.0577 gram of argentic chloride.

	Calculated for $C_6Cl_2[(C_5H_{11})_2N]_2O_2$.	Found.
Chlorine	14.58	14.69

It is evident, therefore, that the diisoamylamine has acted on chloranil in the same way that isoamylamine acted.

Properties of Dichlordidiisoamylamidoquinone, $C_6Cl_2[(C_5H_{11})_2N]_2O_2$. — It crystallizes from alcohol in long reddish black needles. The substance is far from stable, giving off an odor of diisoamylamine on standing in the air, or in a desiccator. If exposed to the air for a long time, it turns first reddish brown, then yellowish brown, and finally becomes an uninviting sticky mass. Owing to this slight stability we are unable to state its melting point with certainty; the highest melting point observed for it was 77°–78°. It is very easily soluble in benzol, ether, ligroin, carbonic disulphide, or chloroform; soluble in alcohol or acetone; insoluble in water. Alcohol is the best solvent for it. It dissolves in strong sulphuric acid, and this solution gives a precipitate, when diluted with water. Cold sodic hydrate has no apparent action on it.

Action of Phenylhydrazine on the Oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$.

When the oxide is warmed gently with phenylhydrazine a yellow substance is formed, which recalls the yellow intermediate body formed by the action of isoamylamine on the oxide. Before we found that isoamylamine led to definite compounds with comparative ease, we devoted a great deal of time to the study of this phenylhydrazine product and its derivatives, but with no results of sufficient certainty to be described, for, although more stable than the yellow isoamylamine compound, this phenylhydrazine derivative is not stable enough to give good results on analysis. So far as our work has led to any formulas they are in harmony with what we should expect from our study of the behavior of isoamylamine.

Hydroxylamine apparently does not act on the oxide.

Dichlordimethoxyquinonedimethyldiacetylacetal,
$C_6Cl_2(OCH_3)_2(OCOCH_3)_2(OCH_3)_2$.

This substance and the ethyl compound described in the next section were prepared for the sake of comparison with the corresponding benzoyl acetals.

3.5 grams of the sodium salt of the dichlordimethoxyquinonedimethylhemiacetal were suspended in acetone, and 2 grams of acetyl chloride added with constant stirring. The action took place to some extent even in the cold, but to complete it the mixture was heated on the steam bath for a short time, until most of the acetone had passed off. The product thus obtained was crystalline, and somewhat colored by chloranilic acid and dichlordimethoxyquinone. It was purified by washing with alcohol, water, and dilute sodic hydrate, to remove sodic chloride, chloranilic acid, and the red substituted quinone, and at last by crystallization from a mixture of chloroform and alcohol, until it showed the constant melting point 177°–178°, when it was dried at 100°, and analyzed with the following result: —

0.2031 gram of the substance gave by the method of Carius 0.1534 gram of argentic chloride.

	Calculated for $C_6Cl_2(OCH_3)_2(OCOCH_3)_2(OCH_3)_2$.	Found.
Chlorine	18.44	18.67

Properties of Dichlordimethoxyquinonedimethyldiacetylacetal. — The substance crystallizes from a mixture of chloroform and alcohol in good-sized white prisms, in which two basal planes are usually so well developed that the crystals look like thick plates. The edges also consist of two basal planes commonly, and the ends of two planes at an obtuse angle to each other. The form seems to be monoclinic. Another very common form consists of rhombic plates with bevelled edges and very sharp acute angles, which are frequently truncated by two planes; the enlargement of these planes forming the edges in the prisms described at first. It melts at 177°–178°.* It is easily soluble in chloroform; soluble in benzol; slightly soluble in ethyl or methyl alcohol, but more soluble in either of these solvents when hot; slightly soluble in ether or acetone; almost insoluble in glacial acetic acid; essentially insoluble in ligroin, carbonic disulphide, or water. A mixture of chloroform and alcohol is the best solvent for it. Sodic hydrate has no apparent action on it.

The most interesting work with this substance was to try to convert it into an oxide similar to the one obtained from the benzoyl acetal. For this purpose it was heated with sulphuric acid of specific gravity 1.44, but the only product which seemed to be formed in these experiments was chloranilic acid; no signs of an intermediate substance could be found. It appears, therefore, that the acetyl groups are far less firmly attached to the molecule in this class of compounds than the benzoyl groups.

Dichlordiethoxyquinonediethyldiacetylacetal,
$C_6Cl_2(OC_2H_5)_2(OCOCH_3)_2(OC_2H_5)_2$.

Six grams of the sodium salt of dichlordiethoxyquinonediethylhemiacetal were suspended in a little acetone, and treated with 3 grams of acetyl chloride with constant stirring. The reaction took place even in the cold, but in order to be certain that it was complete the mixture was heated gently on the steam bath for a few minutes. The product was washed with water, dilute sodic hydrate, and finally with a little alcohol; after which it was crystallized from a mixture of chloroform and alcohol, until it showed the constant melting point 120°–121°, when it was dried, and analyzed with the following results: —

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* The corresponding benzoyl compound melts at 193°.

I. 0.2059 gram of the substance gave by the method of Carius 0.1356 gram of argentic chloride.

II. 0.1740 gram of the substance gave 0.1126 gram of argentic chloride.

	Calculated for $C_6Cl_2(OC_2H_5)_2(OCOCH_3)_2(OC_2H_5)_2$.	Found.	
		I.	II.
Chlorine	16.09	16.28	16.00

Properties of Dichlordiethoxyquinonediacetyldiethylacetal. — This substance crystallizes from a mixture of chloroform and alcohol in very sharp rhombic plates with bevelled edges and the acute angles often truncated. It resembles the methyl compound strongly in crystalline form and habit except that the plates are usually thinner, and it crystallizes even more beautifully. It melts at 120°–121°,* and is soluble in benzol or chloroform; somewhat soluble in carbonic disulphide; slightly soluble in cold methyl or ethyl alcohol, more soluble in hot; insoluble in ligroin, or in water. A mixture of chloroform and alcohol is the best solvent for it. Sodic hydrate has no apparent action upon it.

Action of Sulphuric Acid on Certain Diatomic Phenols.

This work was undertaken in the hope that it might give some help in deciding whether the atom of oxygen in the oxide of dichlormethoxyquinonedibenzoylmethylacetal is in the ortho or meta position; for if by treating ortho or meta diatomic phenols with sulphuric acid we could obtain from one or the other an oxide similar to that which we are studying, there would be a strong probability that the oxygen in our oxide was attached in the same position as that in the new oxide.

The phenols which we have used are resorcine as the meta body, pyrocatechine and some of its derivatives as the ortho compounds, and also chloranilic acid as a representative of the para series.

The sulphuric acid of specific gravity 1.44 used in making the oxide $C_6Cl_2OCH_3O(OCOC_6H_5)_2OCH_3$ had no apparent effect on resorcine, but when it was boiled with an acid of specific gravity 1.71, a reddish brown solution was formed, which deposited a brown mass on cooling; this dissolved in sodic hydrate, and was reprecipitated by hydrochloric acid. From its properties there can be little doubt that it is the resorcine ether $(C_6H_4OH)_2O$, and therefore that two molecules of resorcine have taken part in its formation.

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* The corresponding benzoyl compound melts at 170°.

Sulphuric acid of specific gravity 1.44 had no apparent effect on chloranilic acid.

Sulphuric acid of specific gravity 1.44 did not act on pyrocatechine, and when an acid of 1.84 specific gravity was used the substance was charred. When guaiacol was boiled with sulphuric acid of specific gravity 1.44 for three to four hours, the liquid turned purplish black, and on standing a small quantity of a black amorphous substance separated, which we have not yet succeeded in obtaining in sufficient quantity for identification; but, as it became colorless when treated with zinc and sulphuric acid, and this reduction product was turned yellow by dilute nitric acid, it seems certain that it is not the desired oxide; it probably belongs to the class of quinones. We hope that the study of this body will be continued in this Laboratory in the coming year. In the hope that the loading of the benzol ring with bromine atoms would make the substance more stable, and at the same time encourage the formation of an oxide, since our oxide was prepared from a body with negative radicals on the ring, we next tried the action of sulphuric acid on tetrabromveratrol. With weaker acids no change was observed, but, when it was heated with an acid of specific gravity 1.84, a dark colored solution was formed, and sulphurous dioxide was given off; after dilution with water a red substance was precipitated, which we inferred was tetrabromorthoquinone from its color, and the fact that the sulphuric acid had given up oxygen in forming it. We have not succeeded as yet in obtaining anything resembling our oxide from any of the other brompyrocatechines or their ethers which we have tried.

Tetrabromguaiacol, $C_6Br_4OCH_3OH$.

This substance was made in connection with the work just described as follows. Five cubic centimeters of bromine (a considerable excess over the four molecules required) were added slowly to 2 grams of guaiacol. The reaction was very violent, hydrobromic acid being given off copiously, and before all the bromine had been added the oil solidified to a white mass. After the reaction had been rendered complete by heating for a short time on the steam bath, the product was crystallized from hot chloroform, until it showed the constant melting point 162°-163°.

The same substance was obtained by adding the guaiacol to the bromine. It was dried at 100°, and analyzed with the following result: —

0.2635 gram of the substance gave by the method of Carius 0.4485 gram of argentic bromide.

	Calculated for $C_6Br_4OCH_3OH$.	Found.
Bromine	72.71	72.44

Properties of Tetrabromguaiacol. — It crystallizes from chloroform in long white slender prisms, or thick needles with square ends; and melts at 162°–163°. It is easily soluble in acetone or ether; soluble in ethyl or methyl alcohol, or in chloroform, much more soluble in hot than in cold chloroform; somewhat soluble in benzol, or carbonic disulphide; slightly soluble in glacial acetic acid, or ligroin; insoluble in water. It dissolves easily in an alcoholic solution of sodic hydrate, and in an aqueous solution of sodic hydrate, if it is hot. Acids precipitate the unaltered substance from either of these solutions. When a solution of tetrabromguaiacol in warm glacial acetic acid is treated with strong nitric acid, a red body is formed which we think is tetrabromorthoquinone.

Tribromveratrol, $C_6HBr_3(OCH_3)_2$.

This substance was prepared from tribromguaiacol made by the action of bromine on an alcoholic solution of guaiacol according to Tiemann and Koppe.* 4 grams of the tribromguaiacol were heated in a flask with a return condenser with 0.45 gram of sodic hydrate dissolved in about 50 c. c. of methyl alcohol and an excess of methyliodide. After heating for about an hour the solution was concentrated somewhat on the steam bath, when upon cooling a large quantity of white crystals separated. These were washed with dilute sodic hydrate to remove any unaltered tribromguaiacol, and then with water; after which they were recrystallized from alcohol until they showed the constant melting point 86°–87°, when the substance was dried *in vacuo*, and analyzed with the following results: —

I. 0.2094 gram of the substance gave by the method of Carius 0.3108 gram of argentic bromide.

II. 0.1196 gram of the substance gave 0.1795 gram of argentic bromide.

	Calculated for $C_6HBr_3(OCH_3)_2$.	Found. I.	Found. II.
Bromine	64.00	63.19	63.87

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* Ber. d. chem. Ges., XIV. 2017.

Properties of Tribromveratrol. — It crystallizes from hot alcohol in long slender slightly branched white needles, which when well developed have blunt, perhaps square ends. It melts at 86°–87°. It is easily soluble in benzol, chloroform, acetone, or ethylacetate; soluble in ligroin; somewhat soluble in methyl or ethyl alcohol, or in glacial acetic acid, much more soluble in each of these solvents when hot. The best solvent for it is hot alcohol. Sodic hydrate does not dissolve it, and does not decompose it even when boiling. A warm glacial acetic acid solution of tribromveratrol turns bright red, when strong nitric acid is added to it. If tribromguaiacol is treated in the same way a similar red color is produced, and a bright red substance is deposited on cooling, which we supposed was tribromorthoquinone, but owing to the small yield and the late date at which this work was undertaken we are unable to make any definite statement in regard to it. We hope that the study of this substance will be continued in this Laboratory during the coming year.

Colored Compounds obtained from Substituted Quinones by the Action of Sodic Alcoholates.

The work described in this section was undertaken in the hope of preparing new hemiacetals derived from the substituted quinones, and also of throwing more light on the nature of quinhydrone and phenoquinone. It was abandoned before it had reached a satisfactory conclusion, because of the appearance of two papers by Astre,[*] in which he described substances similar to those made by us; but we give an account of it here, as it has led us to differ from Astre in regard to the constitution of these bodies.

In the paper [†] on hemiacetals derived from quinones, Grindley and one of us state that the first product of the action of sodic phenylate on chloranil is a green or black substance, which on heating passes rapidly into the red dichlordiphenoxyquinone. As it seemed possible that this might be a diphenylhemiacetal, we spent some time in trying to isolate it; but, although we succeeded in obtaining a dark green substance in the solid state, we were unable to find any method of freeing it from the sodic chloride, which (in addition to dichlordiphenoxyquinone) was always formed by a secondary reaction, since it was very unstable. We next turned our attention to the green compound formed by the action of sodic methylate on chloranil,[‡] as this from its mode of formation and color seemed to be analogous to the phenoxy compound. Here we were more successful. A sample of this green product of the action of sodic methylate on chloranil was washed with equal parts of methyl alcohol and water, which did not decompose it so rapidly as water alone, then with methyl alcohol alone, and finally with benzol. It gave the following result on analysis, after it had been dried *in vacuo*: —

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[*] C. R., CXXI. 326, 530.

[†] These Proceedings, XXX. 423.

[‡] These Proceedings, XXX. 430.

0.1810 gram of the substance gave 0.0418 gram of sodic sulphate.

	Calculated for $C_6Cl_4O_2CH_3ONa$.	Found.
Sodium	7.66	7.48

Our other analyses pointed to a similar composition for this substance and related compounds, but in no other case were we so fortunate as to obtain a sample free from sodic chloride. We should not venture to publish this single analysis, therefore, if it were not confirmed by the results given by Astre, who made a green compound by the action of potassic ethylate in ethereal solution upon quinone, which had the formula $C_6H_4O_2KOC_2H_5$, and a similar substance with alcoholic potassic hydrate, $C_6H_4O_2KOH$. Our attempts to prepare compounds like these for analysis have given us a high appreciation of the experimental skill which Astre has shown in purifying these substances. That his compounds are analogous to ours we think can admit of no doubt; not only on account of the analyses, but from the method of formation and the color.

Astre, however, does not assign to his compounds the formulas given above, but considers that the potassium has replaced one of the atoms of hydrogen attached to the benzol ring, so that the substances contain alcohol or water of crystallization, thus: $C_6H_3KO_2C_2H_5OH$ and $C_6H_3KO_2H_2O$. His principal reason for this is based on his experiment with metallic potassium and an ethereal solution of quinone. In this case he found that hydrogen was given off, and a green compound formed having the formula $(C_6H_3KOOH)_2C_4H_{10}O$, which amounts to a molecule of dipotassic quinhydrone combined with one molecule of ether. The attempt to apply Astre's theory to our compound leads to the inadmissible formula $C_6Cl_3NaO_2CH_3OCl$, and therefore, if his compounds and ours are similarly constituted, his theory must be abandoned. In this case it is necessary to explain his result with metallic potassium and quinone in ethereal solution, and this can be done perhaps by supposing a very minute quantity of water or alcohol to have been present in the ether used. This would have given nascent hydrogen, which would have formed a little quinhydrone; this quinhydrone then, by acting on the potassium, would give its salt and more nascent hydrogen, which would continue the action, until a considerable amount of the potassium salt of the quinhydrone had been formed. As quinhydrone forms salts with the metal probably attached to oxygen,* it is not necessary to assume that the atom of potassium has replaced the hydrogen on the benzol ring in this case. All these compounds, by their mode of formation, marked colors, and slight stability, recall the substances formed by the action of sodic alcoholates on various nitro compounds, (such as trinitrobenzol,† symmetrical dinitrobenzoic acid,‡ bromdinitrobenzoic acid, and bromdinitrotoluol,§) and we think probably belong to the same class. The lamented Victor Meyer had already proposed a theory to account for these substances similar to that of Astre, since he assumed that an atom of hydrogen on the benzol ring was replaced by sodium in these bodies, but it is hard to bring this theory into accord with some of the facts published since it was proposed, and the whole subject needs further investigation.

We shall not describe our numerous experiments in regard to these colored derivatives of the quinones, but content ourselves with simply mentioning the substances observed by us. Chloranil gave in addition to the green compounds with sodic methylate and phenylate already mentioned a similar product with sodic amylate. Trichlorquinone also gave a green product with sodic methylate or amylate. Trichlorquinone, or chloranil, gave a blue compound with a strong solution of sodic hydrate, and we also observed the formation of a blue product from sodic hydrate and quinone before the appearance of Astre's paper. With sodic methylate, or amylate, quinone gave blue substances, undoubtedly similar to the ethylate product analyzed by Astre. Hydroquinone gave a faint bluish green coloration with sodic hydrate in aqueous solution, and a bluish green color when sodic methylate was added to its solution in benzol.

Action of Iodine and Sodic Hydrate on Chloranilic Acid.

We had hoped to extend our work to the reduction product obtained from the ethyl oxide by Grindley and one of us,‖ and accordingly tried to reduce the oxide $C_6Cl_2OCH_3O(OCOC_6H_5)OCH_3$ with hydriodic acid in the way used for the ethyl oxide, but we found that, whereas the ethyl compound was easily reduced, as described in the place cited, the methyl oxide was not at all affected under the same conditions, and no satisfactory result was obtained, even when much higher temperatures were used. To the product of one of these experiments, which contained unaltered oxide and free iodine, sodic hydrate was added, when a yellow body separated, which had the smell of iodoform. This observation led us to try the action of iodine on an alkaline solution of sodic chloranilate, when we found that even at as low temperatures as 50°–60° iodoform was obtained. This was recognized by its melting point, 119°, its odor, its yellow color, and the fact that it crystallized in the hexagonal system, although it appeared in stars like snow-flakes instead of the usual hexagonal plates.

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* Jackson and Oenslager, Am. Chem. Journ., XVIII. 15.
† Lobry de Bruyn, Rec. Trav. Chim. Pays Bas, XIV. 89.
‡ Victor Meyer, Ber. d. chem. Ges., XXVII. 3153.
§ Jackson and Ittner, Am. Chem. Journ., XIX. 199.
‖ These Proceedings, XXX. 442.

The work with the reduction product was begun so late in the year that no definite results were obtained before the close of the Laboratory for the vacation.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE COLORED COMPOUNDS OBTAINED FROM SODIC ALCOHOLATES AND PICRYLCHLORIDE.

By C. Loring Jackson and W. F. Boos.

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ON THE COLORED COMPOUNDS OBTAINED FROM SODIC ALCOHOLATES AND PICRYLCHLORIDE.

By C. Loring Jackson and W. F. Boos.

Presented January 12, 1898.

The work described in this paper is the continuation of a research begun by M. H. Ittner and one of us,* about three years ago, upon the colored products of the action of sodic alcoholates on certain aromatic nitro compounds. For a statement of the work of Lobry de Bruyn and Van Leent, and of Victor Meyer, on this subject, the reader is referred to that paper.* The first object to which we turned our attention was the isolation and analysis of more substances of this class, since only three analyses of such bodies had been published; these three analyses led to the following formulas: —

$C_6H_3(NO_2)_3KOCH_3 \frac{1}{2} H_2O$; † $[C_6H_2(NO_2)_3COOKKOCH_3]_2CH_3OH$; ‡
and $C_6H_2OCH_3(NO_2)_2COONaNaOC_2H_5$.§

As dinitranisic acid had given Ittner and one of us § a comparatively stable compound, when treated with sodic ethylate, we at first tried to prepare similar compounds from it and other sodic alkylates; but a few experiments convinced us that the products from these reactions were too unstable for our purpose. Our attention was then called by one of our associates in this Laboratory to the red substance formed by the action of sodic methylate on picrylchloride, and this has led to the discovery and analysis of the following compounds: —

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* Am. Chem. Journ., XIX. 199.

† Lobry de Bruyn and Van Leent, Rec. Trav. Chim. Pays Bas, XIV. 150.

‡ Van Leent, Ibid., XV. 89.

§ Jackson and Ittner, Am. Chem. Journ., XIX. 210.

$C_6H_2(NO_2)_3OCH_3NaOCH_3$;
$C_6H_2(NO_2)_3OC_2H_5NaOC_2H_5$;
$C_6H_2(NO_2)_3OC_3H_7NaOC_3H_7$;
$C_6H_2(NO_2)_3OC_5H_{11}NaOC_5H_{11}$;
$C_6H_2(NO_2)_3OCH_2C_6H_5NaOCH_2C_6H_5$.

To which should be added a substance formed by the action of aqueous baric hydrate on a solution of trinitranisol in methyl alcohol, probably

$$[C_6H_2(NO_2)_3OCH_3]_2BaO_2H_2,$$

which was also obtained crystallized with ten molecules of water. All of these substances have vivid red colors, and are decomposed by an acid, or more slowly by water, giving the picric ether. They are remarkably stable for compounds of this class.

The study of these substances has thrown some light on their constitution. The only published theory about bodies of this class is the suggestion made by the lamented Victor Meyer in his first paper* on this subject, that they might be formed by the replacement of one of the atoms of hydrogen on the benzol ring by potassium or sodium. According to this view our methyl compound would be formulated as follows: $C_6HNa(NO_2)_3OCH_3CH_3OH$; that is, it would contain a molecule of methyl alcohol of crystallization. Lobry de Bruyn† has brought forward an almost, if not absolutely, conclusive argument against this theory in his observation that sodium does not act on trinitrobenzol, even when in a boiling xylol solution, and therefore that trinitrobenzol cannot contain an atom of hydrogen which can be replaced by sodium. Our work described in this paper furnishes two arguments which confirm that of Lobry de Bruyn. First, it has shown that all of the substances analyzed so far contain according to this theory one molecule of alcohol of crystallization, while the salt without alcohol of crystallization predicted by it ($C_6HNa(NO_2)_3OCH_3$, for instance) has never been obtained. Second, we have found that the methyl compound $C_6H_2(NO_2)_3OCH_3NaOCH_3$ can be heated to 130° without loss of weight, which could not have been the case had it contained methyl alcohol of crystallization, as is required by this theory. While neither of these arguments is so convincing as that derived by Lobry de Bruyn from the action of metallic sodium, they give it a strong confirmation,‡ and we are satisfied therefore that Victor Meyer's theory in regard to these bodies should be abandoned, and that they should be considered as formed by the addition of the sodic alcoholate to the aromatic nitro compound. Whether the alcoholate is added to the carbon of the benzol ring or to the nitro group cannot be determined with our present knowledge, but possibly a way has been opened to decide this question by the discovery of the addition compounds formed from quinone and potassic ethylate or hydrate described by Astre,* $C_6H_4O_2KOC_2H_5$ and $C_6H_4O_2KOH$, and that from chloranil and sodic methylate, $C_6Cl_4O_2NaOCH_3$, obtained by H. A. Torrey and one of us.† These substances, by their striking colors, their formulas, mode of formation, and slight stability, seem to be related to the class of compounds discussed in this paper, and, if this connection can be proved, would show that the alcoholate is added to carbon and not to the nitro group. In continuing work in this direction an attempt will be made to find such substances not derived from quinones, as in quinones a special method of attachment of sodic alcoholate is possible, forming the hemiacetals. This line of work will be pursued in this Laboratory during the coming year. It is worth mentioning that Astre independently of Victor Meyer explained the constitution of his compounds by supposing the hydrogen on the quinone ring had been replaced by potassium, thus, $C_6H_3KO_2C_2H_5OH$, a hypothesis which is inadmissible, as our derivative from chloranil undoubtedly belongs to the same class, and here ($C_6Cl_4O_2NaOCH_3$) no such arrangement of the atoms is possible. The details of this argument will be found in the paper by H. A. Torrey and one of us,† already mentioned.

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* Ber. d. chem. Ges., XXVII. 3153.

† Rec. Trav. Chim. Pays Bas, XIV. 89.

‡ Ittner and one of us (Am. Chem. Journ., XIX. 212) observed that the compound $C_6H_2(NO_2)_2OCH_3COONaNaOC_2H_5$ gave off alcohol when heated, but this obser-

By the decomposition of the corresponding colored compounds with an acid the following new picric ethers were obtained: —

$C_6H_2(NO_2)_3OC_3H_7$, melting point 43°;
$C_6H_2(NO_2)_3OC_5H_{11}$, melting at 68°–69°;

this was made from ordinary isoamylalcohol;

and $C_6H_2(NO_2)_3OCH_2C_6H_5$, melting at 115.°

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vation is of little weight in favor of the theory, since the substance at the same time underwent a far-reaching decomposition, of which the alcohol may have been a product, instead of being alcohol of crystallization.

* C. R., CXXI. 530 (1895).

† These Proceedings, XXXIII. 167.

EXPERIMENTAL PART.

Action of Sodic Methylate on Picrylchloride.

When a concentrated solution of picrylchloride in methyl alcohol was mixed with an excess of sodic methylate also dissolved in methyl alcohol, a mass of beautiful scarlet needles was formed immediately; or, if the solution was dilute, these scarlet needles appeared only upon standing. We first prepared the substance for analysis only by washing with water, in which it is but slightly soluble, and drying on a porous plate. The analysis of this preparation is numbered I. A second portion after being washed with water was recrystallized from methyl alcohol, which partially decomposed it, as white plates of trinitranisol could be distinguished mixed with the scarlet prisms of the new body. This impurity was removed by washing with benzol, in which the scarlet compound is nearly insoluble, but the trinitranisol very soluble. This preparation dried *in vacuo* was analyzed with the result numbered II.

The scarlet compound formed according to Clemm,* when a solution of picrylchloride in methyl alcohol was treated with sodic hydrate, was also prepared, and gave on analysis the result numbered III., which proves that it is identical with the product obtained by the action of sodic methylate.

I. 0.5280 gram of the substance gave, after decomposition with sulphuric acid, 0.1168 gram of sodic sulphate.

II. 0.3518 gram of the substance gave 0.0857 gram of sodic sulphate.

III. 0.1680 gram of the substance gave 0.0410 gram of sodic sulphate.

	Calculated for	Found.		
	$C_6H_2(NO_2)_3OCH_3NaOCH_3$.	I.	II.	III.
Sodium	7.69	7.17	7.89	7.90

The formula $C_6HNa(NO_2)_3OCH_3$ requires 8.68 per cent of sodium.

These results indicate that the substance is formed by the addition of one molecule of sodic methylate to one molecule of trinitranisol. The sodic chloride, which must have been the other product of the reaction, was removed by washing with water in the preparation of the substance.

As, according to the theory proposed by Victor Meyer, this substance must contain a molecule of methyl alcohol of crystallization,

$$(C_6HNa(NO_2)_3OCH_3CH_3OH),$$

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* Journ. Prakt. Chem., [2], I. 156.

we next studied the effect of heat upon it. A sample dried for twenty-four hours *in vacuo* was heated to 100°–110°. After one hour's heating it had lost 0.0002 gram, and upon further heating remained constant. The heat was then increased to 130°–140°, but even at this temperature there was no loss in weight. In view of this experiment it seems impossible to maintain that the substance contains methyl alcohol of crystallization. When the temperature was raised to 165°, the substance decomposed, as was shown by a change in color.

Properties of the Addition Product of Trinitranisol and Sodic Methylate. — It crystallizes from methyl alcohol (with slight decomposition) in prisms apparently belonging to the monoclinic system, of a beautiful scarlet, or perhaps rather vermilion color with a bronze reflex. It decomposes at about 165°, and, if heated in the free flame, explodes with great violence. In the dry state it is comparatively stable, keeping well even when exposed to the air; but in contact with water it is gradually decomposed, forming trinitranisol, which, if the action is very long continued, passes into picric acid. Methyl alcohol dissolves it, but not without decomposition, as some trinitranisol is found mixed with the crystals obtained from such a solution; it is almost insoluble in benzol. Acids decompose it at once, forming a body, which after recrystallization from alcohol melted at 64° and was therefore evidently trinitranisol; methyl alcohol was also set free, as shown by the odor.

Action of Ethyl Alcohol on the Addition Product of Trinitranisol and Sodic Methylate.

This work was undertaken in the hope of deciding whether the addition product contained methyl alcohol of crystallization, as in that case the methyl alcohol must be replaced by ethyl alcohol upon recrystallization from this solvent, whereas, if the second methyl group was not present in alcohol of crystallization, it might either remain in the compound under these conditions, or be replaced by the ethyl group. If, therefore, the methyl compound were unaltered by crystallization from ethyl alcohol, it could not contain methyl alcohol of crystallization. Unfortunately, the experiment showed that the methyl group was replaced by ethyl, and therefore no inference in regard to the constitution of the body could be drawn from this work.

On recrystallizing the methyl compound from ethyl alcohol a substance was obtained closely resembling the original methyl compound in color, crystalline form, and properties, but which gave the following result on analysis after having been dried *in vacuo*: —

0.3012 gram of the substance gave 0.0681 gram of sodic sulphate.

	Calculated for $C_6H_2(NO_2)_3OC_2H_5NaOC_2H_5$.	Found.
Sodium	7.23	7.32

This result seems to indicate that the body is the ethyl compound, but is not conclusive, as the difference between the percentages of sodium in the methyl and ethyl compounds is only 0.46 per cent, and the experimental error may well reach or even exceed this amount in the case of compounds which are so hard to purify on account of their instability. But we do not have to depend on the analysis in this case, as upon decomposing the substance with an acid, and recrystallizing the product from alcohol long nearly colorless needles were obtained, which melted at 78°–79°, and were, therefore, the ethyl ether of picric acid. We hope that further experiments in this direction will be tried in this Laboratory during the coming year.

An attempt to make this ethyl compound direct from sodic ethylate and picrylchloride did not lead to the desired result; a mass of red crystals was formed to be sure, but these dissolved, when treated with water to wash out the sodic chloride, giving a red solution, which gradually turned yellow, and then deposited needles of the ethyl picrate.

Action of Sodic Propylate on Picrylchloride.

A concentrated solution of picrylchloride in benzol was mixed with an excess of sodic propylate dissolved in a little propyl alcohol; a heavy precipitate of red needles was formed, which was washed thoroughly at first with benzol and afterward with water. It was then dried on a porous plate, and at last at 110°, when the following results were obtained on analysis.

I. 0.2960 gram of the substance gave on combustion * 0.4390 gram of carbonic dioxide and 0.1260 gram of water.

II. 0.6223 gram of the substance gave 0.1235 gram of sodic sulphate.

	Calculated for $C_6H_2(NO_2)_3OC_3H_7NaOC_3H_7$.	Found.	
		I.	II.
Carbon	40.79	40.45	
Hydrogen	4.53	4.73	
Sodium	6.54		6.44

The formula $C_6HNa(NO_2)_3OC_3H_7$ requires 36.85 per cent of carbon, 2.73 of hydrogen, and 7.85 of sodium.

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* The substance was mixed with chromic oxide to decompose the sodic carbonate formed.

Properties of the Addition Product of Propyl Picrate and Sodic Propylate. — It resembles the methyl compound closely, but its color is a somewhat lighter red, and it is not quite so stable when exposed to the air. Acids decompose it giving propyl alcohol, recognized by the smell, and the propyl picrate, which has not been described heretofore. Propyl picrate crystallizes in fine nearly colorless needles, melting at 43°, and is easily soluble in all the common solvents. If allowed to stand with water or an acid, it is decomposed with the formation of picric acid.

Action of Sodic Isoamylate on Picrylchloride.

A benzol solution of picrylchloride was mixed with an excess of sodic isoamylate dissolved in a little isoamyl alcohol, and the amorphous orange precipitate formed was washed thoroughly with benzol and afterward with water, and dried at first on a porous plate finally at 110°, when it gave the following results on analysis: —

0.2894 gram of the substance gave 0.0490 gram of sodic sulphate.

	Calculated for $C_6H_2(NO_2)_3OC_5H_{11}NaOC_5H_{11}$.	Found.
Sodium	5.62	5.48

The formula $C_6HNa(NO_2)_3OC_5H_{11}$ requires 7.16 per cent of sodium.

Properties of the Addition Product from Isoamyl Picrate and Sodic Isoamylate. — This substance forms an orange amorphous mass, which is decomposed by all the liquids which dissolve it, so that we could not try to crystallize it. It is essentially insoluble in water or benzol. Acids decompose it, setting free amyl alcohol, recognized by its smell, and amyl picrate.

Isoamyl Picrate, $C_6H_2(NO_2)_3OC_5H_{11}$.

This substance was obtained by the action of an acid on the addition product just described. It was purified by crystallization from alcohol, until it showed the constant melting point 68°–69°, when it was dried *in vacuo*, and analyzed with the following result: —

0.1311 gram of the substance gave on combustion 0.2117 gram of carbonic dioxide and 0.0558 gram of water.

	Calculated for $C_6H_2(NO_2)_3OC_5H_{11}$.	Found.
Carbon	44.14	44.02
Hydrogen	4.34	4.73

Isoamyl picrate crystallizes from alcohol in nearly colorless hexagonal plates, which melt at 68°–69°. It is decomposed by standing with water or acids, but in this respect is much more stable than propyl picrate.

Action of Sodic Benzylate on Picrylchloride.

When picrylchloride in benzol solution was treated with an excess of sodic benzylate, a mass of beautiful red needles was formed, which, after washing thoroughly with benzol and water, was dried on a porous plate, and afterward at 110°, and analyzed with the following result: —

0.3125 gram of the substance gave 0.0470 gram of sodic sulphate.

	Calculated for $C_6H_2(NO_2)_3OC_7H_7NaOC_7H_7$.	Found.
Sodium	5.12	4.87

The formula $C_6HNa(NO_2)_3OC_7H_7$ requires 6.74 per cent of sodium.

Properties of the Addition Product of Benzyl Picrate and Sodic Benzylate. — This substance crystallizes in red needles of a somewhat lighter shade than the propyl compound, and shows a distinct fluorescence. It is also more stable than the propyl compound, since a sample of it stood exposed to the air in a watch glass for some months without any visible change. Water decomposes it, but much more slowly than the other compounds of this class. In this decomposition, as well as in that by an acid, the principal products are benzyl alcohol and the benzyl picrate.

Benzyl Picrate, $C_6H_2(NO_2)_3OC_7H_7$.

This substance, prepared by the action of an acid on the addition product just described, was purified by recrystallization from alcohol, until it showed the constant melting point 115°, when an analysis gave the following result: —

0.3828 gram of the substance gave on combustion 0.6805 gram of carbonic dioxide and 0.1090 gram of water.

	Calculated for $C_6H_2(NO_2)_3OC_7H_7$.	Found.
Carbon	48.90	48.48
Hydrogen	2.82	3.16

Benzyl picrate crystallizes from alcohol, in which it is difficultly soluble, in nearly colorless plates, melting at 115°. It is gradually decomposed by acids, forming picric acid.

Action of Baric Hydrate on Picrylchloride, or on Trinitranisol in Methyl Alcoholic Solution.

When a concentrated solution of picrylchloride in methyl alcohol was treated with an excess of an aqueous solution of baric hydrate, a dense mass of red crystals was formed, which were collected, and washed with water as quickly as possible to prevent the formation and precipitation of baric carbonate from the excess of baric hydrate. The crystals were then dried on a porous plate. Trinitranisol dissolved in methyl alcohol gives the same compound, when treated with aqueous baric hydrate, and as thus a purer product was obtained, we prepared most of our material in that way. Analysis of the air-dried substance gave the following result: —

0.8154 gram of substance gave 0.2394 gram of baric sulphate.

	Calculated for $[C_6H_2(NO_2)_3OCH_3]_2BaO_2H_2 . 10\ H_2O$.	Found.
Barium	16.37	17.26

As this indicated that the substance contained water of crystallization, its behavior when heated was studied.

I. 0.7733 gram of the air dried substance lost 0.1622 gram at 110°–130°.

II. 0.3513 gram of the air dried substance lost 0.0736 gram at 110°–130°.

III. 0.8206 gram of the air dried substance lost 0.1738 gram at 110°–130°.

	Calculated for	Found.		
	$[C_6H_2(NO_2)_3OCH_3]_2BaO_2H_2 . 10\ H_2O$.	I.	II.	III.
Water	21.50	20.97	20.95	21.17.

I. 0.4064 gram of the substance dried at 110°–130° gave 0.1504 gram of baric sulphate.

II. 0.4616 gram of the substance gave 0.1694 gram of baric sulphate.

III. 0.1296 gram of the substance gave on combustion 0.1201 gram of carbonic dioxide * and 0.0259 gram of water.

IV. 0.2654 gram of the substance gave † 31.4 c. c. of nitrogen under a pressure of 753.1 mm. and at a temperature of 20°.5.

	Calculated for		Found.			
	$[C_6H_2(NO_2)_3OCH_3]_2BaO_2H_2$.	$[C_6H(NO_2)_3OCH_3]_2Ba$.	I.	II.	III.	IV.
Barium	20.85	22.06	21.76	21.58		
Carbon	25.56	27.05			25.26	
Hydrogen	1.83	1.29			2.22	
Nitrogen	12.78	13.53				13.40

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* Chromic oxide was used to decompose the baric carbonate formed. The substance was spread out in a long copper boat, and heated very carefully to avoid explosions.

† The substance was mixed with sand to decompose any baric nitrite which might have been formed.

These results, therefore, do not decide with certainty between the two formulas, for, although the percentage of carbon speaks strongly in favor of $[C_6H_2(NO_2)_3OCH_3]_2BaO_2H_2$, the determinations of barium agree better with the percentage calculated for the second formula. As the most probable impurity in the substance was baric carbonate, we shall adopt the formula containing baric hydrate provisionally.

Properties of the Addition Product of Trinitranisol and Baric Hydrate. — It forms needles of a fine red color verging toward scarlet. When heated to 110°, it loses its water of crystallization, and turns a beautiful dark crimson, but the dried salt absorbs water very eagerly from the air, regaining its scarlet red color. This fact necessitates great care in handling the dried salt during the process of analysis. Part, but not all, of the water of crystallization is given off *in vacuo*. It is insoluble in water. Acids decompose it, giving trinitranisol, but no alcoholic odor was observed.

Calcic hydrate added to a solution of picrylchloride in methyl alcohol gave a red precipitate, but this decomposed almost immediately with formation of trinitranisol. Dinitranisic acid dissolved in methyl alcohol gave a magnificent purple coloration, when treated with aqueous baric hydrate, but the substance formed was very unstable. It is mentioned here, as it forms an additional argument for classing the trinitranisol compounds described in this paper with the colored derivatives of dinitranisic acid discovered by Ittner and one of us.

The work will be continued in this Laboratory.

Proceedings of the American Academy of Arts and Sciences.

Vol. XXXIII. No. 11. — February, 1898.

THE ANALYSIS OF THE ACTION OF THE VAGUS NERVE UPON THE HEART.

By Dr. L. J. J. Muskens.

THE ANALYSIS OF THE ACTION OF THE VAGUS NERVE UPON THE HEART.

PRELIMINARY NOTICE.

By Dr. L. J. J. Muskens, Assistant in Physiology, Harvard Medical School.

Presented by H. P. Bowditch, January 12, 1898.

In a former investigation, carried on in 1895–96 in the laboratory of Prof. Th. W. Engelmann in Utrecht, I was enabled to demonstrate that there exist reflexes from the point of the ventricle upon the centrifugal nerves of the different parts of the heart, the reflex centres being in the medulla oblongata.* These reflexes were for the most part standstills, similar to those produced by striking the intestine of the frog (Reflex of Goltz). In studying these reflexes I found that, during the so called standstills, frequently only the ventricle stops, the auricle meanwhile, or still more frequently a certain part of the sinus, continuing to beat, with perhaps a slight retardation, sometimes even with increased frequency. My research work with Dutch frogs convinced me that this phenomenon must be ascribed to a decreased conducting power. By the influence of the Vagus nerve the passage of the contraction wave over the heart muscle can be blocked. It became clear that the conduction of the peristaltic contraction is a function of the heart, which up to the present time has been too little regarded, especially in the German and French literature on the subject. As to the literature in the English language, there is the admirable work of Gaskell upon the action of the Vagus in the tortoise,† and those of McWilliams, and of Bayliss and Starling, on the innervation of the mammalian heart. Moreover, the conducting power of the heart has received attention from Engelmann, Wesley Mills, G. N. Stewart, Knoll, Reid Hunt, and Harrington. The surprising fact that, in a subject so thoroughly studied as the physiology of the Vagus, this most important function has received such slight attention and is so imperfectly understood, may be due to the not less surprising circumstance, that students of the physiology of the heart have in a peculiar manner overlooked the more central parts of the organ, the very source of the heart revolutions, viz. the large veins. Especially is this the case with regard to the influence of nerves upon the heart. Most investigators have contented themselves with observing simply the ventricle. Gaskell and Engelmann and Bayliss and Starling recorded systematically the movements of the ventricle and the auricle: no one thus far has studied the influence of nerves of cold-blooded animals upon ventricle, auricle, and sinus, recording the movements of all these parts at the same time. Knoll very recently did so with great skill in the mammalian heart; the conditions are there, however, much less favorable for an analysis of the Vagus action, as it has been found by me to exist in the case of the amphibian heart. By simply recording the movements of the sinus alone under Vagus action, this part of the heart proves to be capable of quite complicated forms of activity. The Vagus is able to dissociate the movements of the large veins in a manner well adapted to throw light upon the cause of the normal heart-beat. While the auricles and ventricles undoubtedly perform the most important functions in the mechanical work of maintaining the circulation, we have to look upon these portions of the heart, as far as their rhythmical motions are concerned, as under the control of influences proceeding from the large veins. In regard to this point, the study by Engelmann of the muscular properties of the sinus, published in 1896,* and Tigerstedt and Stromberg's previous work on the same subject, are to be consulted.

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* Royal Dutch Academy of Sciences, Session of Oct. 26, 1896, and Pflüger's Archiv., Band LXVII. p. 135.

† Journal of Physiology, Vol. IV. p. 43.

A second important point in which my experimental work differs from that of my predecessors is, that I forsook the customary method of excising the heart with the adherent Vagus nerves. In both series of experiments, in Holland as well as in America, I have been able to show that the functions of the heart, and still more the normal action of the Vagus, are injuriously affected by the least lack of normal nutrition. I have, therefore, taken the greatest care, in employing the suspension method of Engelmann, to attach the different parts of the heart to the recording levers in such a way that the circulation through the heart and the body was interfered with as little as possible. The slightest loss of blood is constantly followed by changes in the force, and still more by changes in the conducting power of different parts of the heart. It is easy to prove that the diminished force of the ventricular contractions in Vagus stimulation as studied by Heidenhain and Gaskell can be observed only in cases of imperfect nutrition caused, for instance, by loss of blood. There is no reason to believe that the Vagus nerve has any influence upon the force of the normally nourished ventricle or upon that of the normally nourished veins, although a negative influence of Vagus stimulation upon the force of the auricle seems to be a constant effect. The phenomena described by Heidenhain and Gaskell may perhaps belong in the same category as the "staircase" of Bowditch; at all events, I could in the American bull-frog (R. Catesbeiana) easily demonstrate, as an effect of stimulation after bleeding, a rapid decrease or disappearance of the ventricular contractions, which simulates a standstill. After this standstill the contractions came gradually back to their former force. The same staircase-like phenomenon can, after somewhat more prolonged anæmia, be observed also in the auricle, not, however, in the large veins.

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* Pflüger's Archiv., Band LXV. p. 109.

A third point in my experiments which may be worthy of mention is the manner in which I stimulated the Vagus. I needed to find a method which can be used without any operation or loss of blood. Moreover, it was desirable to stimulate both Vagi, as one often finds them not equally effective. For this purpose a special instrument was constructed, which is to be fixed in the Tubæ Eustachii, and which will hereafter be fully described. Of the details I will mention here merely that twenty-four hours before the experiment the animal received a small dose of curare, which was insufficient to cause complete paralysis. It may also be mentioned, that I have made a special study of the analysis of physiological standstills, which last from some seconds to half a minute. In frogs, with good reflex irritability, treated as above described, one very often sees, without any stimulation, spontaneous standstills. These normal standstills never last so long as, for instance, those observed by Gaskell with prolonged faradization. I have avoided these standstills, in the conviction that in that way new factors are introduced, viz. insufficient nutrition during and after a standstill.

The analysis of the dromotropic * and of the chronotropic † effect of the Vagus upon the different parts of the heart is attended with the greatest difficulties. The further the analysis proceeds the more it becomes obvious that phenomena apparently belonging to the chronotropic effect can

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* Influencing the conducting power.

† Influencing the frequency of the contractions.

be referred to dromotropic influence. With more refined methods of recording cardiac phenomena, it is extremely probable that the importance of the dromotropic as compared with the chronotropic influence will be found to be still greater than it can now be shown to be. The stimulation of the dromotropic fibres of the Vagus causes dissociation in the activity of the different cavities of the heart, affecting the conduction of the contraction wave, not only between auricle and ventricle and between sinus and auricle, but even between the component parts of the sinus itself. The effects upon the conduction between sinus and auricle and between auricle and ventricle are very often in an opposite sense.

The interference of accelerator and retarding nerves upon the heart, investigated by Bowditch, Ludwig, Baxt, and Hunt, may find its interpretation in the dromotropic action of the Vagus.

In this preliminary notice it seems impracticable to give more details; the results, with the discussions to which they lead, will be published in full in the "American Journal of Physiology."

Boston, December 20, 1897.

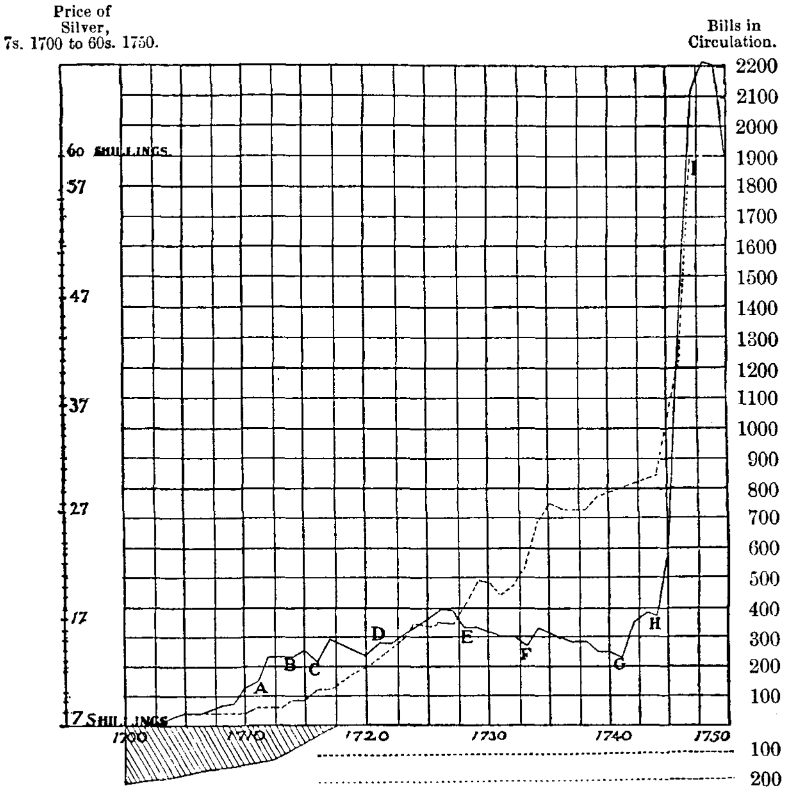
Proceedings of the American Academy of Arts and Sciences.

Vol. XXXIII. No. 12. — February, 1898.

CERTAIN CONSIDERATIONS CONCERNING THE COINAGE OF THE COLONY AND THE PUBLIC BILLS OF CREDIT OF THE PROVINCE OF THE MASSACHUSETTS BAY.

By Andrew McFarland Davis.

DIAGRAM SHOWING DISAPPEARANCE OF SILVER, INCREASE OF PROVINCIAL CURRENCY AND CORRESPONDING MOVEMENT OF SILVER RATE, 1700-1750.



Volume of Currency ————————

Price of Silver ....

A. Quebec Expedition, £30,000 Loan.
B. £50,000 Loan.
C. £100,000 Loan.
D. £50,000 Loan.
E. £60,000 Loan.
F. Merchants' Notes.
G. W. I. Expedition. Land Bank.
H. Cape Breton Expedition.
I. Price of Silver checked by proposed reimbursement.

Unit of Scale of Silver Price one shilling.
Unit of Scale of Circulation £1,000.
The shaded block underlying the currency represents the Silver Circulation in New England.
The years are indicated along the base line between Currency and Silver.

CERTAIN CONSIDERATIONS CONCERNING THE COINAGE OF THE COLONY AND THE PUBLIC BILLS OF CREDIT OF THE PROVINCE OF THE MASSACHUSETTS BAY.

BY ANDREW MCFARLAND DAVIS.

Presented June 9, 1897.

THE New England shilling was, according to the terms of the Act establishing a Mint,* to be of the just alloy of new, sterling, English money, and for value to be twopence in a shilling of lesser value than the corresponding English coin. It was to weigh three penny-weights, Troy weight. Like the guinea, this shilling is to-day a mere reminiscence, yet until a very recent period it held its own in many parts of New England, in the price lists of tradesmen, as the sixth of a dollar. Douglass says: † "At the first settling of the New England Colonies, their medium was sterling coin at sterling value, and barter. When they got into trade a heavy piece of eight passed at 5*s*. A. 1652, they proceeded to coin silver shillings, sixpences, and threepences, at the rate of 6*s*. to a heavy piece of eight." There is no reference to the value of the piece of eight in the Act establishing a Mint, but it will be seen that the conversion of the New England shilling into sterling would have been on the basis of exchange at 120, whether the rate be estimated from the corresponding values given in the Act in pence, or from those given by Douglass in pieces of eight. Douglass, however, states elsewhere,‡ that the actual value of the piece of eight was only 4*s*. 6*d*. If this was so, then the New England shilling was from the outset worth only ninepence and the normal rate for the conversion of New England currency to sterling was 133. These are the rates that prevailed during the period of the Province, and the only question is whether the shilling ever did have the value of tenpence according to the language of the act. The heavy piece of eight not only passed within the Colony at five shillings in early days, but, according to Douglass,* it was remitted to Great Britain on that basis. This being the case, it is easy to understand how the law makers came to rate a piece actually worth only ninepence sterling at tenpence, an effective value accomplished through the remittance of pieces of eight at a rate above their market value, and we need no explanation for its decline from this nominal rating to its proper place in the scale of exchange, so soon as the immediate causes which led the London tradesmen to accept this discrimination against them should have passed away.

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* Mass. Col. Rec., Vol. III pp. 261, 262.

† A Discourse concerning the Currencies, etc., p. 10. In addition to the above coins, silver twopences were authorized in 1662. Mass. Col. Rec., Vol. IV. p. 51.

‡ A Discourse, etc., p. 8.

The mint was established in the hope of retaining a metallic currency in the Colony, through the agency of the lighter coinage, but it was soon evident that it was not performing this work, and in August, 1654, a law was passed against the exportation of coin.† Mere legislation, however, was no more effective than the system of coinage, and in May, 1669, searchers were appointed with extraordinary powers whose duty it was to examine outgoing vessels which had weighed anchor with the intention of leaving our waters.‡ They were to seize all money which they should find, and were invested with power to break open packages and examine personal effects. Notwithstanding these arbitrary proceedings silver still left the country, and in October, 1672, the General Court prefaced an Act legalizing the currency of pieces of eight with a preamble in which it was stated that these coins were of more value to carry out of the country than they would yield at the mint. and, what was of more consequence, that they were actually carried out of the country instead of being taken to the mint. To prevent this, it was ordered that pieces of eight, of full weight and good silver, Mexico, Seville, and Pillar, should pass current at six shillings, after they had been duly stamped at the mint with the letters N. E. to indicate that they had been inspected.§ Light weight pieces of eight were to be stamped with their actual weight, and to pass for a proportionate value.

This is the first point at which we obtain a legal rating of the piece of eight in New England currency, and it might be inferred that this value was assigned in consequence of the depreciation of the coinage from the rate at which it was originally minted. If this opinion should prevail, the date of this Act will be accepted as that at which the value of ninepence sterling was recognized as the true value of the New England shilling. It seems much more probable, however, that the Act was the result of two circumstances: first, that, the piece of eight having a recognized value, people could and did avail themselves of it as a medium of trade without paying seigniorage at the mint for its conversion into New England money; and second, that the General Court was desirous of protecting the public against the light weight pieces, if possible. So far as this latter reason may have had influence in promoting this legislation, it is evident that it produced little result; for in May, 1682,* the General Court authorized the currency of light weight pieces of eight according to their weight. Under the Province, it was enacted in 1692 that pieces of eight, Seville, Pillar, and Mexico, should pass current if of full seventeen penny-weight at six shillings, and this value was again assigned them in 1697.† The expression "full seventeen penny-weight," is probably the equivalent of "not less than seventeen penny-weight." The rate of silver per ounce to be deduced therefrom is a little over seven shillings. The same year the legislation against the export of bullion or money was renewed,‡ and shipmasters on clearing were required to take an oath that they did not have on board their vessels over five pounds in bullion or current silver money.

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* A Discourse, etc., p. 8.

† Mass. Col. Rec., Vol. III. pp. 353, 354.

‡ Mass. Col. Rec., Vol. IV. p. 421.

§ Mass. Col. Rec., Vol. IV. p. 533.

In 1704, a proclamation was issued by Queen Anne fixing the rates at which certain foreign coins should pass current in her Majesty's dominions in America. The weight and intrinsic value of these coins were given, and also the rates at which they should pass in the Plantations, the latter being fixed in terms of New England currency. It may be inferred from this proclamation and the parliamentary statute passed in 1706 for enforcing it, as well as from colonial legislation, both before and after this date, with regard to the value at which pieces of eight should pass, that the New England coinage had been supplanted by the Spanish and Mexican dollars and fractional parts thereof. The mint had been closed for twenty years when the proclamation was issued, and thenceforth New England money when used to express silver values was known as "proclamation money" or "lawful money," equivalent expressions, found in the acts of the several governments, meaning nothing more nor less than the rate fixed at which coined silver should pass when measured in terms of the New England currency.* By this proclamation, the Seville piece of eight, old plate, and the Mexican piece of eight, were each valued at 4*s.* 6*d.* and the weight of each was given at 17 dwt. 12 grs. The Pillar piece of eight was given a slightly higher value in this table. The rate at which these coins were to circulate was fixed at 6*s.* the same value as that assigned by the provincial legislation "if of full seventeen penny-weight." The rate of conversion was exactly 133, the 4*s.* 6*d.* sterling being equal to 6*s.* New England money. The rate for silver in London was then 5*s.* 2*d.* per ounce. At $17\frac{1}{2}$ dwt. for the piece of eight, silver was rated at 6*s.* $10\frac{2}{7}$*d.* per ounce, or at a fraction less than 5*s.* 2*d.* sterling.

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* Mass. Col. Rec., Vol. V. p. 351.

† Province Laws, Vol. I. pp. 70 and 296.

‡ Province Laws, Vol I. p. 306.

The Provincial Act of 1697 seems to have been the basis for the rates fixed in the proclamation. In 1706, the Lords of Trade informed Governor Dudley that this was the fact. "You are further to represent to the Assembly," they said,† "that there lies a particular obligation on them to enforce a due obedience to her Majesty's commands herein, for that the regulation of the rates at which foreign coins are to pass was calculated from a law of their own." The establishment of the value at which foreign coins should pass in the Plantations, by the standard fixed for the value of the New England shilling in an Act passed by the General Court of Massachusetts, instead of reversing the process and taking sterling money as the basis, at first glance seems peculiar. It must be remembered, however, that at that date, apart from the fact that the Province was dependent upon foreign silver for its currency, New England money was to a great extent but a nominal measure of value, the mint having been closed for over twenty years and the Province having been compelled in the mean time to resort to legislation against the export of silver, in order to keep within its borders the miscellaneous coins then in circulation. Moreover, the circumstances connected with the silver coinage in Great Britain at that time were such as may serve to some extent to explain this readiness to accept a measure of value set by the Province itself in terms of a foreign coin. The table of values for foreign coins contained in the proclamation was prepared by

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* Felt, on page 116 of his Historical Account of Massachusetts Currency, says, "As debtors, who confided in the last emission of Government notes, had promised to pay lawful money, meaning these bills. . . . " This expression is susceptible of the interpretation that Felt thought the public bills of the issue referred to were lawful money, which may or may not have been his intent. The statute which he was interpreting was passed for the purpose of relieving debtors who had incautiously agreed to pay lawful money for debts incurred in public bills.

"The Editor has been unable to find any definition or explanation of what is meant by 'proclamation money.'"—New Hampshire Prov. Papers, Vol. V. p. 672.

† Province Laws, Vol. I. p. 580.

Sir Isaac Newton, who had been called to the charge of the mint for the purpose of superintending the recoinage of the silver of the realm. Prior to this process and during its continuance, the relations of the values of English gold and silver coins were greatly disturbed. After the recoinage, confidence was re-established in London, but it was still fresh in the minds of men that the upward career of the guinea, when measured in the clipped and sweated silver in circulation prior to this measure, had been decreed by parliamentary enactment to stop at 30*s*., and that by successive laws its measure in silver had been ordered to be reduced to 22*s*., while as a matter of fact it had, at the time the table was made, actually fallen to 21*s*. 6*d*. Thus it will be seen that the recent instability of the English silver coinage may have influenced the politic course taken in accepting the measure of value, established in terms of a foreign coin, by the colonists themselves. The rate having been thus fixed between a nominal measure of values and an actual coinage, there was nothing to disturb it, and it was passed on to our day, six New England shillings being equal to the dollar, Mexican or Spanish, and to their successor, our own dollar, 133*s*. New England money being in the days of the Province equal to 100*s*. sterling.

Until dollars came into use, all transactions in Massachusetts were stated in New England money. All accounts given in terms of "lawful money" must therefore be reduced twenty-five per cent if we would obtain the corresponding amount in sterling. During the progress of the currency inflation which took place in this country in the first half of the eighteenth century, the Province of the Massachusetts Bay was the leader. The other New England Colonies copied the form of note first issued in this Province, which was in effect a mere certificate that the bill was due from the Province to the possessor and should be in value equal to money, and on these terms would be accepted by the Treasurer in all public payments. The bills of the different governments circulated side by side promiscuously, even after legislation was invoked to prevent it, no matter what the terms on which they were issued or the amounts outstanding of the bills of the several governments, and when they all of them became so seriously depreciated that they were worth only about twenty-five per cent of the value at which they originally circulated, Massachusetts adopted a new form of bill in which the value of the bill was expressed in coined silver or gold. The other Colonies also adopted the new form, and bills of the respective forms were thereafter known as old and new tenor bills. Of the new tenor bills Massachusetts used three different forms, but they all preserved the feature of stating a value in silver at which the bill should pass, though changes were made in the silver rate and in the phrase which defined their use in payments. The new tenor bills were at first held at the rate of one for three, but very shortly thereafter the fact that the depreciation of the old tenor bills was not fully recognized in this estimate compelled the establishment, when the second form of new tenor bills was adopted, of the ratio of one to four. Old and new tenor bills were sometimes emitted, side by side, in the same Act, and thus it became necessary that one of these forms should be accepted as the measure of value. Inasmuch as all values had been stated in old tenor up to the issue of the new form, and as there were for a short time two forms of new tenor having different measures of value in old tenor, it was *customary for writers to convert the bills of the new tenor into old* tenor in making statements of the amount in circulation. When, therefore, it is stated that there was in circulation in 1749 £1,900,000 of public bills of the Province of the Massachusetts Bay, it must be remembered that, if the taxes which were laid for the purpose of withdrawing from circulation the old tenor bills had been paid exclusively in these bills, there would have been in circulation at that time only £475,000 in bills of the different forms of new tenor, and exchange, instead of being 1100 or thereabouts, would have been *only* 275. While such facts as these add greatly to the confusion of the situation, no just appreciation can be acquired of the statements which I am about to submit, showing the movements of exchange, etc. during this period of inflation, which does not take into consideration that in 1737 these disturbing elements were introduced through the emission of the new tenor bill.

The following table, showing the rate of exchange and the price of silver at different dates, 1702 to 1749, was made up by Dr Douglass.*

Periods.	Exchange with London.	1 oz. Silver.	Periods.	Exchange with London.	1 oz. Silver.
A. D. 1702	133	6s. 10½d.	A. D. 1728	340	18s.
1705	135	7s.	1730	380	20s.
1713	150	8s.	1737	500	26s.
1716	175	9s. 3d.	1741	550	28s.
1717	225	12s.	1749	1.100	60s.
1722	270	14s.			

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* Douglass's Summary, Historical and Political, etc., Vol. I. p. 494.

The Suffolk files furnish us with two papers which give the fluctuations in silver somewhat more in detail than the foregoing table between 1700 and 1738, inclusive. This record is copied from a book kept by Edward Winslow, who was sheriff of Suffolk County, and it has therefore a certain official character.*

Years.	Rate of Silver per Ounce.	Years.	Rate of Silver per Ounce.	Years.	Rate of Silver per Ounce.
1700 to 1704	7s.	1721	12s. 6d., 13s., 13s. 6d.	1731	18s. 6d., 19s.
1705 to 1710	8s.	1722	14s.–14s. 6d.	1732	19s. 6d., 20s., 20s. 6d.
1711	8s. 4d.	1723	14s. 6d.–15s., 15s. 6d.	1733	21s., 21s.6d., 22s., 22s.6d., 23s.
1712, 1713	8s. 6d.	1724	16s.–16s. 6d.		
1714, 1715	9s.	1725	16s.–15s.	1734	24, 25, 26s., 26s. 6d., 27s.
1716, 1717	10s.	1726, 1727	16s.	1735	27s. 6d.
1718	11s.	1728	16s. 6d.–17s., 18s.	1736	27s., 26s. 6d.
1719	12s.	1729	19s.–19s. 6d, 20, 21, 22s.	1737	26s. 6d., 27s.
1720	12s. 4d.	1730	21, 20, 19s.	1738	27s.

From scattered sources we can fill in the missing quotations from 1738 to 1749, with sufficient accuracy for our purposes.† As to the rate of exchange at the latter date, the confusion was so great that no person knew just what it was, but silver was generally quoted at about 60*s.*, and exchange at about 1100. In 1700, the Province was practically on a specie basis, and exchange was quoted at its normal rate, 133. Douglass gives silver in 1702 at 6*s.* 10½*d.* Hutchinson practically adopts the same rate.‡ If the piece of eight was permitted to circulate on the basis of 17 dwt. the rate of silver was 7 $\frac{1}{17}$*s.* per ounce. If the conditions of the proclamation of 1704 were adhered to, then the rate was 6*s.* 10$\frac{2}{7}$*d.* per ounce. The general rating of the period appears, however, to have been that given by Winslow, 7*s.* per ounce. A committee of the General Court recommended that pieces of eight should pass at 7*s.* per ounce, in 1701.* Another committee in 1703 † proposed that plate, bullion, and silver of sterling alloy should pass at 7*s.* per ounce. Seven shillings may therefore be adopted as the generally accepted value at that time.‡

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* Suffolk files, 40,289 and 46,659. There is a table incorporated in the draught of an act which failed of passage, given in the Massachusetts Archives, Vol. CI., p. 473, which includes the rates from 1710 to 1727. Another is to be found in the Diary and Letters of Thomas Hutchinson, p. 53. Felt gives the table from the Archives, Historical Account of Massachusetts Currency, p. 83.

† The important points being 1744, 30*s.*; 1745, 36*s.*; 1746, 41*s.*; 1747, 60*s.*; 1750, 60*s.*

‡ History of Massachusetts, Vol. II. p. 393.

All through the Provincial legislation 6*s.* 8*d.* is treated as the normal rate of silver in lawful money, and 5*s.* 2*d.* as the sterling rate. With exchange at 133, and silver rated at 5*s.* 2*d.* sterling, the rate in lawful money should have been 6*s.* 11*d.*, a fraction above the rate to be derived from the proclamation. The question naturally arises, Whence came this rate of 6*s.* 8*d.*? My conjecture is that it dates back to the days of the Colony, at which time silver is sometimes quoted at 5*s.* § This sterling rating would be the equivalent of 6*s.* 8*d.* New England money. Its use would in that event have been merely traditional, but a traditional rate might have fixed itself upon a denominational money.

During the period of the decline of the notes, the influence of the Governors and of the Councillors, especially after the decline became sufficiently pronounced for them to recognize the causes, was as a rule on the side of conservatism. They had no remedy to propose, but the Governors in their speeches repeatedly pointed out the evils which would arise from failure on the part of the Assembly to call in the notes at the appointed time, and the Council many times refused to concur in bills which by their terms postponed the withdrawals. The effect of the decline was felt most by individuals living upon salaries, or having fixed incomes payable in current funds, but it also reached certain branches of the government. The post office, for instance, was dependent for its support upon a schedule of fixed charges, and no compensation was possible for the loss occasioned by the decline of the currency. In 1713, the department lodged a complaint with the Board of Trade, for this reason.* The Governors not infrequently pointed out that the allowances made them for their services ought to be increased proportionately to the diminution in the purchasing power of the bills, and the members of the Board and of the House took care that their *per diem* pay was at least approximately adjusted. "I own, some part of this community can fence against this evil," said Governor Shute, in 1716, "and ward it off from themselves by advancing their commodities, but the other part must unavoidably suffer. All rents must fall of consequence, and what will your ministers do, who are highly worthy of their salaries? how heavily it will fall upon them and their families, when what they are paid in grows low in value, and their necessaries of life are daily advancing." Douglass saw that through the changes made in the allowances to the Governors and in the *per diem* pay which the members of the General Court voted to themselves, a sort of scale could be constructed with which to measure the diminution of the purchasing power of the bills, and he therefore put together the following table.†

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* Mass. Archives, Vol. CI. p. 184.

† Court Records, Vol. VII. p. 373.

‡ The author of "Observations on the Scheme for £60,000 in bills of a new Tenour," p. 18, gives the rate in 1702 at seven shillings. The same author, however, in "An Inquiry into the Nature and Uses of Money," etc., p. 4, gives the rate the same year as eight shillings. December 27, 1704, Dudley announced that he had received the proclamation. Court Records, Vol. III. p. 95. On the 3d of March, 1704-5, the Council passed an order that no money should pass by tale but what was of due weight, according to her Majesty's proclamation. Light money and plate of sterling alloy were to pass until further provision should be made at the next session of the Assembly at seven shillings per ounce. The House non-concurred, and the Governor summoned them to a conference. After the conference, the order was amended by striking out the seven shillings, and making it read that light weight coins, etc. should pass and be good in payments by the ounce Troy *pro rata* until the end of the session of the Court in May. Court Records, Vol. III. p. 113. On the same day Dudley issued a proclamation to that effect. Mass. Archives, Vol. CI. pp. 287 and 290.

§ A Discourse, etc., p. 24. Douglass, speaking of the effect of the depreciation of the currency on the salaries of clergymen, says the preachers "when silver was at 5*s.* had £3 per week; at present, silver at 29*s.* per oz., they have only £6 to £8, equal to 40*s.* of former times."

A. D.	1702.	1720.	1730.	1740.	1743.	1745.	1747.	1748.
Gov'nors	Dudley	Shute	Belcher	Belcher	Shirley	Shirley	Shirley	Shirley
Per Ann.	£600	£1,000	£2,400	£3,600	£5,400	£6,000	£7,600	£9,600
Councillors per day	5s.	6s.	10s.	15s.	18s.	18s.	30s.	40s.
Representatives per day	3s.	4s.	6s.	10s.	12s.	12s.	20s.	30s.
Rates	£6,000	£6,000	£6,000	£35,000	£60,000	£120,000	£168,324	£381,672

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* Board of Trade Journal, quoted by Palfrey, Vol. IV. p. 332.

† Douglass's Summary, etc., Vol. I. p. 508.

The growth of the rates or annual charges of the government is almost as instructive as the advance of the pay of the legislators, but is of course complicated by causes outside the currency. The changes in the pay of the Councillors and Representatives, as laid down in the Province Laws, are as follows.

A. D.	1692.	1714.	1728, 1737.	1738, 1740.	1741.	1742, 1746.	1747.
Councillors per day	5s.		10s.	15s.	12s.	18s.	30s.
Representatives per day	3s.	4s.	6s.	10s.	8s.	12s.	20s.

It will be seen that the records practically confirm Douglass's table, so far as the *per diem* pay of the legislators is concerned, the brief variation in 1741 not being of sufficient importance for consideration. The increase in the Governor's pay in 1748, would indicate a probable increase at the same time in the pay of the Councillors and Representatives; but there is no record preserved of any action on this point. The Annual Tax Acts all contain statements of the amounts respectively levied for the Province tax and for Representatives' pay and fines. If the service of the Representatives had been uniform each year, we could test the table by a comparison of the appropriations for Representatives' pay for different years; but an examination of these amounts from year to year shows that the growth to be found there does not exactly follow the law which would be deduced from the amount of the *per diem* pay. It is a fact, however, that while the amount assessed in June, 1747, for Representatives' pay and fines, was £2878 11*s.* 6*d.*, the corresponding amount in the levy next year was £4508 5*s.* The presumption is that Douglass was correct in the figures which he gave for the pay of the Councillors and Representatives in 1748.

A variety of circumstances complicates the attempt to analyze the allowances made the Governors during this period, but on the whole Douglass's table fairly represents the changes. Phips had three annual allowances of £500 each. Bellamont, who was very popular, had two allowances of £1000 each. Dudley was allowed £500 in 1702. Shute was at first allowed £1200, but this was afterwards cut down to £1000. Belcher's first allowance was £2400, from 1731 to 1737 inclusive he was allowed £3000, then for three years the sum was fixed at £3600. From this point Shirley's allowance was advanced by stages to £5400, £5760, £6000, £7600, and finally it was, in 1748, £9600.

It was stated by a contemporary writer that there was in circulation in the four New England Colonies, when the first issues of Province bills were made, about £200,000 in silver.[*] Douglass says that in 1713,[†] one third in value of the circulating medium of the New England governments was silver, and the other two thirds paper. The bills he estimated at £175,000. Silver was then rated at 8*s.* per ounce. They were therefore equivalent to 437,500 ounces of silver. He called them 438,000 ounces, and thus got a total of 657,000 ounces. A comparison of some of these estimates may be useful.

Year.	Silver in Circulation.	Bills in Circulation in all New England.	Rate of Silver per Ounce.	Corresponding ounces of Silver in Circulation.	Value of Circulation at 6s. 8d. per Ounce.
		£			£
1700	£200,000		7s.	571,428	190,476
1713	219,000 oz.	438,000	8s.	657,000	219,000
1718		300,000	12s.	500,000	166,666
1731		470,000	20s.	470,000	156,666
1739		630,000	29s.	434,482	144,827

If there is any rule to be deduced from the foregoing table it would seem to be substantially the same as that laid down by Douglass: [‡] "The more paper money we emit, our real value of currency or medium becomes less, and what we emit beyond the trading credit of the country does not add to the real medium, but rather diminishes from it by creating an opinion against us, of bad economy and sinking credit."

The apparent exception to the rule, in the excess in the purchasing capacity of the circulation shown in 1713, may be capable of explanation. When the Colony began the emission of public bills of credit there was in circulation an amount of silver practically adequate for the transactions of local business affairs. Until it had been totally displaced and superseded by paper money, any estimate of the amount remaining in circulation at any given time must have been conjectural. Douglass's estimate of one third in circulation in 1713 may have been too high, and was indeed disputed by one of his contemporary controversialists. Whether this be so or not, time was required for the emissions to produce their effects upon the discount of the bills and the displacement of silver, and it is quite probable that the £50,000 emitted for the Hill and Walker expedition against Quebec in 1711 had not then fully done its work. Still another exception to the rule is to be found in 1749. There were outstanding that year, in the month of May, about £2,200,000 old tenor. A tax of £75,000 new tenor was laid that summer. This was equal to £300,000 old tenor, and reduced the amount outstanding to £1,900,000. Silver was then quoted at 60*s.* an ounce, and the outstanding circulation, thus reduced, was equivalent to 633,333 ounces, which at 6*s.* 8*d.* an ounce was equal to £211,111. It must not be forgotten, however, that when that tax was laid it was known that the government of Great Britain had completed its preparations for reimbursing the Province for its expenditures in behalf of the Cape Breton expedition, and a law had been passed in the Province fixing the terms of the redemption of the bills. One cause of the delay in paying over the money to the Province was the opposition of certain merchants in London, who believed that speculators were gathering in the bills in the hope of reaping a profit out of their redemption. These exceptions, therefore, do not furnish adequate reasons for doubting the correctness of the rule deduced by Douglass.

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[*] The Second Part of South Sea Stock, p. 22.

[†] A Discourse, etc., p. 29.

[‡] A Discourse, etc., pp. 29, 30.

The influence of large emissions on the part of the Province of the Massachusetts Bay upon the silver quotations can be easily distinguished, and in some instances, where the rise of silver was stimulated by causes not connected with the issues of this Province, the coincidence with large emissions in Rhode Island furnishes an adequate explanation of this change in rate. Douglass was of opinion that two thirds of the bills emitted by Rhode Island were absorbed in the circulation of Massachusetts. The table on the opposite page, mainly made up from facts brought together by Douglass in his pamphlets, will illustrate these points.

Wages did not rise proportionately with silver. In a pamphlet published in 1721, when silver was between 12 and 13*s.* an ounce, the writer says,* "I will next ask the poor laborer that works for five shillings per day, half money, half goods, whether he lives better now than when he received four shillings per day in good silver money at the rate of seventeen penny-weights for six shillings." Douglass, writing in 1739 concerning the effect of the depreciation on wages, says:† "How much they have suffered and continue to suffer is obvious. For instance, a carpenter, when silver was at 8*s.* per oz., his wages were 5*s.* a day all

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* The Second Part of South Sea Stock, p. 16.

† A Discourse, etc., pp. 23, 24.

Year.	Rate of Silver per Ounce.	Loans and Extraordinary Emissions.
1700	7s.	
1706	8s.	
1712	8s. 6d.	£50,000 advanced acc. Quebec Expedition.
1715	9s. 2d.	£50,000 loan, 1714. £40,000 R. I., 1715.
1717	12s.	£100,000 loan.
1722	14s.	£50,000 loan, 1721. £40,000 R. I.
1728	18s.	£60,000 loan, 1727. £40,000 R. I., 1728.
1732	21s.	£60,000 R. I. loan, 1731.
1733	27s.	£76,000, 1733; £104,000, R. I.; £50,000 Conn.
1738	29s.	£100,000 R. I. loan.

cash. The Town House, A. 1712, was built at this rate; whereas at present, A. 1739, from the bad influence of paper money, silver being 29*s.* per oz., he has only 12*s.* a day, equal only to 3*s.* 4*d.* of former times; and even this is farther reduced, by obliging him to take one half in shop goods at 25 per cent or more advance above the money price." He then proceeds to show how the purchasing power of the day's wages has diminished, selecting butter for his illustration on the ground that it rose the most uniformly of all provisions. When wages were 5*s.* per day, butter was 4*d.* per pound, and the laborer could buy 15 pounds with one day's wages. His 12*s.* would only purchase 7 pounds, butter being then 20*d.* a pound. The salaries of clergymen had more than doubled, but the purchasing power of the salaries had diminished thirty-three per cent.

There is much to be learned from a study of the attempts at remedial legislation during this period. The subject of the adjustment of the relations between debtors and creditors, and the application of the legal tender function to the bills, raised complications which occupied much of the time of the General Court, and the various attempts to reconcile the divergent interests of the debtor and creditor classes are entitled to careful consideration. The material bearing upon these questions is, however, too prolific for any attempt at analysis here.

The form of the public bill has already been indicated. It was in effect a certificate of indebtedness, and on that theory, when it found its way back to the treasury, the debt was extinguished and the temporary function of the bill was performed. Under this theory the amounts originally issued each year were simply intended to meet the immediate needs of the government, and provision was made for their retirement in the next tax bill. The withdrawal from circulation, and the locking up in the hands of a treasurer, of large sums collected by taxation, is recognized as a serious disturbance to the circulating medium of a government, and various devices are to-day resorted to in order to prevent as far as possible the consequent reduction of the circulation. In a similar way, after the country became dependent for a circulating medium upon the amounts thus annually emitted, the sudden emission and the withdrawal each year of so large a proportion of the medium of trade must have created a serious disturbance in commercial affairs, and the cry of a scarcity of bills during the period of the year when the taxes were being collected was based upon a genuine want, even when the bills were most abundant. The increase in the amounts issued, the postponement of the periods for retirement, and the distribution of the withdrawals over several years, were only partial remedies for this evil. Confidence in the bills was based upon their ultimate withdrawal, and the greater the emissions the greater the taxes that must be levied to provide for their retirement. While this was evidently true, and while there were indications that pointed to a loss of confidence in the bills when the Assembly failed to provide the promised fund for the withdrawal of an emission, yet it cannot be doubted, however paradoxical it may seem, that whenever a fund was called in for the purpose of redeeming the government promises and maintaining confidence in the bills, it was expected that there would be an emission to fill the gap thus occasioned in the circulating medium.

The emissions in Massachusetts from 1702 to 1749 reached the sum of £4,630,000, while the withdrawals during the same period, including the £300,000 in 1749, were £2,730,000. It was doubtless to overcome the disturbance occasioned by this annual process of absorption and emission, that the system of distributing bills of public credit among the inhabitants, on loans secured by real estate, was resorted to. £310,000 was thus put out at different times. The first loan was to the Boston merchants who furnished supplies for the Quebec expedition in 1711. This was only a temporary loan, to enable them to carry the sterling exchange paid to them by the paymasters of the expedition, until it should be met in London. In 1714, when it was about to be paid, it was replaced by a loan of £50,000 to the inhabitants of the Province. When the first instalments on this loan fell due, in 1716, £100,000 was put out and this was followed by £50,000 more immediately after the last instalments on the first popular loan were payable, in 1721. When by the terms of these loans they should have been retired, a new loan of £60,000 was made, and doubtless this process would have been continued but for the interference of the Board of Trade. The meaning of the attempt is obvious. The Assembly was seeking to furnish a medium for trade, which should not be subject to the annual calls for retirement under which bills for government expenditure were issued.

Among the various experiments then made there were but two attempts to give these bills a credit based upon a promise that they should be paid in coin, the first being of little consequence, as it applied to only £1500 emitted in 1693.* The promise in this, as well as in the later and more important instance, was not on the face of the bill, but was in the Act of emission, and in the second case was so worded that in practical operation it did not prove beneficial for the bills in question. The Act under which the £9,000 in bills of the first new tenor were emitted in February, 1736–7, contained a provision for levying a tax in 1741, adequate for their retirement, payable not only in the bills themselves, but in old tenor bills or in certain produce. It was further provided that after that session, and until 1742, the duties of impost and excise should be paid in coin, and although it was thought that the several funds established for the retirement of the outstanding bills would be adequate for the purpose and all would be out of the way by that time, these duties were pledged as a still further security. If by chance it should happen that any of these new tenor bills should be outstanding at any time after December 31, 1742, the possessor was to be entitled to receive from the treasurer for every six shillings and eightpence in these bills, an ounce of silver or the like value in gold. All of the first new tenor bills were issued with this promise of redemption in December, 1742, attached, and all of them were declared to be in value equal to silver at six shillings and eightpence an ounce, an estimate which was above the true rating of silver based upon sterling exchange, as has already been pointed out, and also above the rate at which the bills circulated, as appears from the discussions which subsequently took place in connection with the adjustment of debts. These bills were declared to be worth three times as much as bills of the corresponding denominations of the old tenor form, and were to be received by the treasurer on the basis of one of the new tenor for three of old tenor. In January, 1741–2, when the second new tenor form was first issued, the bills were rated in the Act on the basis of one of the form mentioned in the Act for four of old tenor, no provision being made in the Act for their redemption in coin. From that time until December, 1742, the Province saw circulating side by side two forms of bills, each declared to be equal to silver at six shillings and eightpence an ounce, one of these forms being rated in the statutes at a premium of 33 per cent above the other, and the bill that was at a discount having behind it a specific pledge for its redemption in coin within less than twelve months. It was also true that at the same time Rhode Island bills issued on twenty-year loans, to an amount vastly disproportioned to the resources of the Colony, when compared with the circulation of the Massachusetts bills, were freely received at a premium above these first new tenor bills. It is possible that the discredit in which these bills were held during the spring and summer of 1742 was intentional, for the Assembly, just in time to save the credit of the Province, made provision for the exchange of such as were outstanding December 31, 1742, on terms nearly equivalent to their redemption in coin. Thus ended this absurd attempt to give credit to the public bills by *promising to redeem in silver and gold such as were outstanding* after the fund provided for their withdrawal from circulation was closed. How far it may have affected public opinion at the time, and prevented a more liberal and reasonable attempt at the establishment of a currency redeemable in coin on demand, must be a matter of personal judgment, but it will be admitted that this experience was capable of an interpretation in the hands of those hostile to such a movement which would have militated against any such experiment.

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* The delusive promises to be found in some of the later Acts of emission, to the effect that the silver and gold which should be received for commodities turned in by tax collectors were to be held for the benefit of possessors of bills, were not entitled to grave consideration.

I have prepared and submit herewith a table showing the various amounts annually emitted, inclusive of loans from 1702 to 1750. In parallel columns with these, the amounts retired each year and the amount left outstanding are given, the withdrawals being made up on the assumption that the loans were called in when due. It is known that this was not the case, but it would be impracticable to attempt to follow these payments in detail. It is also known that the tax collectors were at times delinquent in their returns, so that the funds provided for the withdrawal of the bills were not collected according to the terms of the legislation, but in the long run these things took care of themselves. The emissions in the table are procured from the Acts and Resolves of the General Court. The Tax Acts furnish the withdrawals or retirements. The figures to be obtained from this table correspond in their final result with those given by contemporary writers as to the amount outstanding in 1749. There are some fragments of treasurer's statements and some committee reports showing the amounts outstanding at different dates. These reports require examination before they can be applied to test the accuracy of this table. The treasurer was apparently accustomed to charge himself with all bills which were emitted against future funds, but the bills intended for loans he charged to the commissioners of the loans, and they made their reports direct to the Assembly. The treasurer's reports, therefore, as to the amount of bills outstanding at any given date require correction by the addition of the loans then outstanding to the net amount with which he stands charged after having deducted from the emissions the credits to which he was entitled. For instance a report, the bulk of which is given by Felt,* shows that up to November 11th, 1724, the treasurer stood charged with bills amounting to £397,006 1*s.* During the interval which his statement covered, there had been paid in £194,917 2*s.* 10*d.*, which had been burned by committees of the General Court, and there was in the treasury at that date £10,558 12*s.* 1*d.*, leaving outstanding according to this statement £191,530 6*s.* 1*d.* Now there were actually outstanding at that time the entire amounts of the £100,000 loan and the £50,000 loan of 1721, and in addition thereto the taxes were to a great extent pledged for several years ahead as funds for the retirement of bills which must then have been in circulation. The estimate of the amount outstanding to be found in my table, which is made up from the Acts and Resolves of the General Court, shows £326,000 in May. If we add the £150,000 loans to the treasurer's statement we get £341,000 in November. This difference might easily be explained, but not all the comparisons of the figures to be obtained from these reports with the estimates given in the table will turn out so favorably as this.

The diagram setting forth the disappearance of the silver circulation of the Province and the line of growth of the currency shows also the corresponding movement which took place in the price of silver, all values being stated in the old tenor currency of the Province. Had it been possible to sustain the bills at par until the amount in circulation was equal to the silver in use in 1700, we should have had the starting point for the curve of the silver rate at the date when the emissions were in excess of the trading wants of the Province. The circumstances of the Province necessarily controlled and limited its trading capacity. A greater amount than was needed could not have been kept in circulation. Hence the maintenance at par of an adequate substitute for the silver could only have been attained by the displacement of that metal. If the currency had remained at par up to the point suggested, there would have been no necessity for considering the relations of the increase of the currency to the decrease of the silver. Each emission of bills would have required the displacement of a corresponding amount of coin in order that it should circulate. As a matter of fact, however, the rise of silver began almost as soon as the Province adopted a form of bills of its own. Up to 1702, use was made of the Old Colony bills, to meet by emissions the extraordinary wants of the Province. The adoption at that date of a form of bill specially adapted to the use of the government was a practical announcement that the policy of emitting public bills was to be continued, and was followed so promptly by a rise in silver that the quotation in 1704 shows an advance of a shilling. The displacement of silver was apparently slower in taking effect, so that it would appear that the bills increased slightly the purchasing capacity of the circulation for a few years.

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* Historical Account of the Massachusetts Currency, p. 80.

The graphic delineation of the disappearance of the silver is based upon the statement of one of the pamphleteers of the day as to the amount of silver required for the trade of New England,* and the assertions of Dr. Douglass that there were 219,000 oz. still remaining in circulation in 1713 which had entirely disappeared in 1718.† Since the disappearance of the silver was practically simultaneous throughout New England, the only effect of adjusting this representation to the proportion in use in Massachusetts alone would be to reduce slightly the area included between the two curves. The main features would be the same.

With regard to the time of the disappearance of silver, it is not improbable that the £100,000 loan at the end of 1716, following so closely on the £50,000 loan of 1714, caused the coin to be hoarded in 1717. Then came the process of adjustment, through which the silver rate reduced to its just proportion a paper medium having a nominal valuation in excess of the trading needs of the Province. When distrust and lack of confidence added the force of their weight, this reduction actually brought the purchasing capacity of the bills in circulation, notwithstanding the great excess of their denominational value, below the amount formerly deemed essential for the use of the Province.

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* The Second Part of South Sea Stock, p. 22.

† A Discourse, etc., p. 29.

By reference to the table showing the coincidences between certain movements in the price of silver and emissions of large amount by this Province and the Colony of Rhode Island, the dates of some of the Rhode Island loans can be obtained. A glance at the diagram will disclose the effect of these emissions, but it is desirable for the full appreciation of this effect to take note of certain facts in connection with affairs in Massachusetts at the same time. A contemporary writer* says, in 1740, that the highest point which the Massachusetts currency had then reached was in 1721. This statement would be true, if no consideration were had of the £50,000 loan made that year; but when this is borne in mind, the culminating point prior to 1741 would seem to have been in 1726. The necessity of including the emissions of the other governments, if we would deduce any law from the subject under consideration, is forcibly illustrated by the divergence, between 1727 and 1741, of the lines which mark the currency volume on the one hand, and the silver rate on the other. Under pressure from the Board of Trade the Provinces of the Massachusetts Bay and New Hampshire were not only prevented from further increasing their public bills of credit during this period, but were actually compelled to reduce the amounts in circulation. Meantime Rhode Island had flooded the Province with emission after emission of public bills, some issued upon funds, but nearly all loaned out at interest for terms varying from ten to thirteen years, and then to be liquidated in annual instalments covering ten years more. Of these bills there were £340,000 outstanding in 1741, the greater part of which were in circulation in Massachusetts. Owing to their presence, the Assembly of this Province had witnessed the silver rate advance from 16*s.* in 1727 to about 29*s.* in 1741, in the face of the fact that the circulation of their own public bills had been reduced from £396,000 in 1726 to £229,000 in 1741. The purchasing capacity of the bills of the Province in circulation, rated in silver at 6*s.* 8*d.* per ounce, had through this cause been reduced from £165,000 to less than £53,000. Attempts had been made, without success, to prevent the circulation of the bills of the neighboring governments. The Colony of Rhode Island was drawing a revenue from the interest of the loans. The borrowers were able, in turn, to

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[*] An Inquiry into the Nature and Uses of Money, p. 19.

lend in Massachusetts the public bills which they thus secured at a higher rate of interest than that charged by the Colony, so that they in turn made a profit. The privilege of obtaining shares in these loans commanded a ready sale at a premium. Douglass quotes the premium on the privilege to subscribe to the £100,000 loan in 1738 at 35 per cent. To all of this the people of the Province of the Massachusetts Bay had to submit, through the obstinacy and stupidity of the traders, who insisted upon giving currency to the Rhode Island bills.

The rate of silver should naturally have gone in 1748 above seventy shillings, but the belief that the expenses of the Cape Breton expedition would be reimbursed must have held it in check. Certainly this must have been the case after the passage of the Act in January, 1748–9, providing for the future redemption of the bills, if the coin should be received by the Province in settlement of the claim for reimbursement. Furthermore, this Act contained arbitrary measures for the prohibition of the circulation of the bills of the other governments, and this again had a tendency to reduce the silver rate.

The addition of another line to the diagram, showing the volume of the entire currency in circulation, including the contributions of the other governments, might perhaps have added to its interest. It will not be difficult, however, to make use of the figures heretofore given to obtain an approximate result of this sort. In its present shape, the diagram brings forth vividly the peculiar condition of this Province, just prior to the inflation under Shirley, when suffering vicariously for the sins of Rhode Island. The Province had responsibilities enough of its own to bear in this connection, and it is well that so much of the burden as can be lifted shall be deposited where it belongs.

EMISSIONS AND RETIREMENTS MAY 1 TO MAY 1, INCLUDING LOANS.

Year.	Emissions.	Retirements.	Outstanding.	
	£			
1702	5,000	£	£	
1703	32,000	6,000	5,000	
1704	32,000	22,000	31,000	
1705	22,000	22,000	41,000	
1706	40,000	26,000	41,000	
1707	32,000	22,000	55,000	
1708	32,000	22,000	65,000	
1709	46,000	. . . .	75,000	
1710	44,000	22,000	121,000	
1711	95,000	. . . .	143,000	£50,000 loan, acc. Quebec Expedition.
1712	25,000	22,000	238,000	
1713	14,000	22,000	241,000	
1714	64,000	47,000	233,000	£50,000 loan to inhabitants of Province. The payment of the loan acc. Quebec Expedition was about this time. Withdrawals arbitrarily assigned to the years 1714 and 1715.
1715	8,000	47,000	250,000	
1716	111,000	32,000	211,000	
1717	9,000	32,000	290,000	£100,000 loan passed Dec. 4, 1716. Emitted 1717. The £50,000 loan of 1714 was to be paid in five annual instalments, £10,000 each 1715-1719 inclusive.
1718	11,000	32,000	267,000	
1719	15,000	26,000	246,000	
1720	65,000	27,000	235,000	
1721	17,000	16,000	273,000	£50,000 loan to towns, to be drawn in by taxes, 1726-1730 inclusive.
1722	45,000	16,000	274,000	
1723	40,000	17,000	303,000	
1724	55,000	25,000	326,000	
1725	70,000	30,000	356,000	
1726	25,000	39,000	396,000	£100,000 loan expired in 1727. £50,000 loan to towns, paid in instalments, 1726-1730. £60,000 loan to towns, to be paid in taxes in the years 1734-1738 inclusive.
1727	88,000	142,000	382,000	
1728	36,000	39,000	328,000	
1729	20,000	30,000	325,000	
1730	13,000	30,000	315,000	
1731	24,000	24,000	298,000	
1732	. . . .	26,000	298,000	
1733	79,000	21,000	272,000	
1734	27,000	47,000	330,000	£60,000 loan withdrawn by taxes.
1735	39,000	58,000	310,000	
1736	48,000	59,000	291,000	
1737	81,000	81,000	280,000	
1738	26,000	62,000	280,000	
1739	. . . .	. . . .	244,000	
1740	80,000	95,000	244,000	
1741	120,000	. . . .	229,000	
1742	117,000	86,000	349,000	
1743	85,000	95,000	380,000	
1744	344,000	115,000	370,000	
1745	1,040,000	140,000	599,000	
1746	741,000	124,000	1,499,000	
1747	268,000	168,000	2,116,000	
1748	400,000	415,000	2,216,000	
1749	. . . .	300,000	2,201,000	
1750	. . . .	. . . .	1,901,000	
Total	4,630,000	2,729,000		

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THE BASIS OF THE SCIENCE OF POLITICAL ECONOMY.

By Edward Atkinson.

THE BASIS OF THE SCIENCE OF POLITICAL ECONOMY.

BY EDWARD ATKINSON.

Presented March 9, 1898.

I HAVE asked the opportunity to present a treatise upon the basis of the science of political economy, because there are many masters of the physical or exact sciences who deny the existence of such a science of social relations. It is held by the writers on what is called political economy that it relates to the production, distribution, and consumption of wealth. I do not think the name is well chosen, and I should vary that definition somewhat in the following terms: the science of the production, distribution, and consumption of the means of existence and of material welfare. If there is no science, then there are no fundamental principles constituting the basis of action of human beings in the maintenance of human life. If that is true, then material life rests wholly upon chance. Is there any such thing as chance in the universe in which humanity is a part? Is there not even a law of chances governing the accidents of life? Does not order prevail everywhere? Then, if order prevails in the provision for human wants, it must rest on fundamental principles. The definition of a principle in this connection would be, "a rule of action among human beings," — "a demonstrated truth that requires no further proof." I shall venture to present the evidence that certain rules of action have governed human beings from prehistoric times, and certain facts which are of the nature of demonstrated truths.

Man is the only trading animal. Other animals co-operate in tribes for mutual protection and to some extent for common sustenance, but none exchange product for product or service for service; none trade. No other animal except man has invented money as a medium of trade. It is therefore a rule of action governing human beings after they emerge from the merely animal stage, that they exchange services; they trade.

The law of commerce is the law of mutual benefit. The motive of commerce must at first have been an intellectual perception that by an exchange of products both parties benefited. There may no longer be any distinct intellectual action or separate and special conscious perception of mutual benefit actuating each transaction; nevertheless, the motive of trade is a purely metaphysical perception of the fact that by an exchange of material things the work of sustaining material life is lessened.

The next fact which requires no further proof is the admitted fact that general moral welfare is only consistent with general material welfare. The essential wants of men must be supplied as a condition precedent to the development of moral faculties. It is of no use to preach to men with empty stomachs.

In the support of material existence, or in dealing with the products on which material life depends, and in treating the exchanges of these products by which general welfare is assured, we then find the three fundamental principles of a science governing the actions of men: the material, the metaphysical, and the ethical. Such is the trinity of trade.

As I have said, if there are no principles or rules governing human action in the supply of human wants on which a science can be based, it would follow that material existence rests wholly upon what we call chance. But is there any such thing as chance in the universe? If order prevails in the supply of the wants of men, then have we not the basis of a science?

Another admitted fact that requires no further proof is, that all men make a demand upon the means of existence, and all men must be supplied with food, — most men with clothing and shelter. Where shelter and clothing require no effort, mankind remains in the animal stage until aroused by trade. Society has recognized the right of this demand, and furnishes the supply of shelter, food, and clothing to the incapable, but to no others, except in exchange for some service rendered. Again, is it not true that all that any man can get out of material products or things are food, clothing, and shelter? What more does the rich man consume? what less will suffice for the poor man? The cost of the capitalist is what he consumes; his service is what he adds by his ability to the general product. Yet this science, applied to the supply of wants and dealing wholly with material subsistence and with physical conditions, is, as I have said, a purely metaphysical science. The motive which actuates commerce is personal benefit, — a purely intellectual conception. Apparently that is a selfish motive, yet every exchange implies, of necessity, two parties in every transaction. Each is governed by the same motive, to wit, his own benefit. It follows as a scientific demonstration that all commerce is, to use a bad modern phrase, *altruistic*, whether those who conduct it are conscious of the fact or not. It may not be uniformly beneficial, but is yet *altruistic*. The demand of the ignorant man may be for something that does him harm, yet he seeks what he believes to be his own benefit. For instance, in buying quack medicines he thinks he is benefited by partaking of the sarsaparilla in Ayer's compound. What he really gets is twenty-six per cent by volume of alcohol, — in Hood's sarsaparilla about nineteen per cent. In other words, he secures a stimulant more active than sherry or Madeira wine, perhaps even in this way to his benefit. Dealings in noxious or fraudulent compounds are, however, very small relatively to the dealings in materials necessary to existence.

Again. I have stated that man is the only animal that has invented money. Money is a medium of exchange, a necessary tool in the conduct of commerce, which is for mutual benefit. All records, prehistoric and modern, prove the existence of commerce and the use of money. If I am rightly informed, the recent discoveries in Assyria and Babylonia prove the existence of a wide commerce, of which many of the terra-cotta plates give the records. The standard of that period has been stated to me by Professor Lyon as what might be called a silver "bob." That fact brings up a difficult problem. It would appear that silver existed in sufficient quantity to serve as a money metal four thousand years before Christ. It is proved by the Old Testament Scriptures that the shekel or weight of silver in the time of Abraham — about 2500 B. C., I believe — was the money of the merchant. Yet no deposits of native silver have ever been discovered of sufficient magnitude to supply even a small coinage. Native gold and native copper have been found in large quantities, and have served for monetary use; but silver is at the present time the product of complex processes of smelting and separation from the ore. Whence came this prehistoric silver? Did smelting and assaying exist and for a time become a lost art?

At a later period, when cattle constituted the medium of exchange, did the silver disappear, or did cattle, being more abundant and silver relatively difficult to provide, displace silver as money of the known world at that time? The evidence of the use of cattle for monetary purposes extends from Asia into Scythia, thence across the whole of Europe, even into Ireland. The tariff of the lawful charges of the physician or of the cleanser and bather is given in the Zend-Avesta in terms of cattle, among which female slaves are counted.

Then gold appears again, or rather a natural alloy of gold and silver known as electron, which, according to Ridgeway, — whose recent book upon coinage and weight measures is based upon the methods of evolution, as distinguished from the development of coinage under the application of the higher mathematics, — had begun to circulate in the form of dust or nuggets passing by weight before the invention of coinage. He presents a good deal of proof that the first coin made of electron in Lydia, about 700 B. C., was equated with the cow at about one hundred and thirty-five grains of this alloy. He cites the proof of the common use of the bull's head and other signs upon the early coins. Thence coinage was carried into Greece, where the gold stater, or standard, or unit of value, was first coined by Philip of Macedon at a very similar weight; and that gold stater was for a very long period the standard or unit of the world's commerce of that period.

Again. There are few races of men so low in intellect as not to have invented money, choosing the many articles with which you are familiar which have for the time being served the purpose. At a later period came the invention of the decree or law of legal tender. From the dawn of history to the present time this conception of a legal tender born in fraud and nursed in corruption has been made use of to debase the coinage in order to cheat the masses of the people, or else for the collection of a forced loan, as in the instances of the Continental currency of our Revolutionary time and of our legal tender currency of the present day. The only exceptions to this rule regarding legal tender have been specific laws passed for the purpose of keeping the small change or subsidiary coinage within the limits of the country by which it has been coined, as a token of light weight in metal, redeemable in coin of full value. In these facts we surely find the basis of a science.

It is proved that in the very earliest stages of civilization men have invented money and have used it as a medium of commerce. Commerce rests upon mutual benefit. From period to period the thing used for money has changed, passing through various stages. Non-metallic subjects, such as cattle, stock fish, shells or cowries, wampum, leather, tobacco, furs and skins, have been adopted. Metals in useful forms, like hoes in Africa, have been used. The several metals iron, copper, silver, and gold have been used, one successively displacing the other with the progress of wealth and with the enlargement of commerce. In the end gold has become by a process of natural selection, and in total disregard of legislation, the unit or standard of the world's international commerce. For that purpose it is used now under a weight name, "pound sterling." There is no lawful coin of that name. The equivalent is named a sovereign. Pound sterling is now the definition of 113.0016 grains of gold, having originally been the name of a pound Easterling of silver, based on the Troy or Troyes table of 5760 grains, which was the standard of the Steel Yard where foreign goods were held in stock for sale in England. Drafts and agreements made in the term of pound sterling can be liquidated and discharged only by the delivery of the exact weight of metal; thus coming back to the original conditions under which the precious metals served as money by the definition of weight, — the shekel, the mina, the drachma, and others. No conception of an act of legal tender could have entered the mind of any legislator or ruler, so long as the weight standard and the weight of coins were consistent. The only possible purpose of an act of legal tender in early times, down through the Middle Ages, and until the present century, was in fraud of the masses of the people upon whom light weight or base coins were forced. In these facts, do we not find the basis of monetary science?

Again. I have referred to the three elements or fundamental principles, rules of action governing human beings, upon which modern commerce has been progressively developed.

The first, the material necessity for the means of existence.

The second, the metaphysical perception of the benefits of exchange.

The third, the moral habit engendered out of these conditions.

I use the term "moral habit" as something distinct from conscious moral effort. Sir Henry Maine calls attention to the fact that the trust which is necessary to the conduct of commerce in all its branches is a very modern conception. In the Homeric records, the cunning of Ulysses and habits of fraud and deception are as meritorious and worthy of praise as the wisdom of Nestor or the courage of Achilles. Maine uses a phrase in respect to modern conditions substantially in the following form: "The trust imposed in and deserved by the many creates the opportunity for the fraud of the few." This becomes very manifest whenever the present conditions of trade are passed in review.

I have computed the value of our annual product at approximately two hundred to two hundred and twenty-five dollars' worth per head of food, fuel, materials for shelter, and clothing, at the present time. These are first produced in their crude form from the field, the forest, and the mine. They are passed in the process of trade or exchange to the converters or manufacturers, so called; thence to the wholesale dealers; thence to the retail dealers. In respect to many articles there are as many as ten different trades or transactions between the original producer and the consumer. The average cannot be less than three. Under these conditions, the volume of trade which is necessary to the supply of human wants in this country only without which modern society could not exist, comes to not less than one hundred million dollars every day in the year, including Sundays. It is in fact more.

Now, in proof that a moral habit has of necessity been engendered in the conduct of this traffic, it is a well established fact that it would not be worth twenty-five cents on a hundred dollars for the nation to guarantee the prompt payment of every obligation or trust incurred in the process of this trade. The dealers, the bankers, the merchants, could not afford to pay a guarantee of twenty-five cents on a hundred dollars.

You will bear in mind, by the way, that all that any man can get in a material sense in this life by means of this method of production and distribution is his board and clothing, no matter how rich he is. But into that branch of the subject I do not propose to enter.

I have said that the very existence of society can only be conceived on the basis of this mutuality of the service of commerce. Its benefits are gained in exact proportion to the freedom of trade, whether among the people of one country or between countries. Protective tariffs have to some extent interfered with commerce between this and other countries, and have given for the time being a misdirection to a small part of our energy. On the other hand, absolute freedom of trade among the States has been assured by the constitutional provision thereto.

Now, what are the facts developed under this system, which have become "admitted truths requiring no further proofs," and may therefore be taken as the basis of a principle? The people of this country have enjoyed absolute free trade among the greater number and over a larger area than have ever enjoyed that natural condition before. What is their condition relatively to other countries? The resources of the European continent are as great as those of our country. The resources of South America, with perhaps the exception of coal, on which I am not informed, are as great as those of North America. Yet the material progress of the people of the United States puts all other countries or nations in the shade. It has been vastly greater. Moreover, it is becoming an admitted truth, requiring no further proof since the publication of Wright's Report on Prices and Wages for Fifty-two Years, that under the influence of these conditions those who perform the manual, mechanical, and farm work of this country — the working classes, in the narrow sense — have secured decade by decade an increasing proportion of a constantly increasing product, and have become the most prosperous people in the world, taken as a whole; better served in every respect with railways and waterways, and while numbering only five per cent of the population of the globe, consuming between thirty-three and forty per cent of the iron, steel, and copper; twenty-eight per cent of the cotton;

and twenty-five per cent of the wool; also consuming such a wasteful abundance of food, that in spite of waste we feed others to nearly half our own number.

I therefore venture to submit the claims of political economy to recognition, not only as a science, but as the science to which all the physical sciences are subordinate, except as pursuits for those who, being sustained in their material existence by the efforts or work of others, devote the whole time to pure science, without regard to its application. Yet without the application of science to the pursuits of peace, order, and industry, could even the devotion to pure science be justified? There is but one department of philosophy to which we must all bow, and that is the science of law. None can attain the place of the true jurist who deals with rights and establishes the conduct of society on the foundation of rights. Yet political economy emulates the science of law in bringing to the gradual conviction of mankind the sense of the fact that rights must be sustained in order that the greatest material prosperity and the greatest physical welfare of humanity may be secured. Moreover, the science of political economy is not only a handmaid of jurisprudence, but the foundation of liberty. In the interchange of services the greatest benefit ensues. The greatest benefits are gained where the utmost freedom is permitted, subject to restriction only for police purposes or for the protection of the public health. The motto of the social scientist and of the political economist, if there is a distinction to be made, may rightly be, "Liberty and Law," — freedom to use but not abuse the opportunities which year by year are widened and extended, opening broader fields and more numerous ways to the attainment of the common welfare.

"Of what avail the plough or sail,
Or land or life, if freedom fail?"

I had completed the essay of which this is a digest some time ago; and on reading it aloud, one of my sons remarked the close analogy to Kant's essay upon Eternal Peace. I confess that I was surprised and gratified to find that I had been an unconscious plagiarist of so great a man. There is a close analogy between the conclusions which I have derived from the experience of this free country, and the wonderful prophecy which Kant uttered a hundred years ago regarding the necessary effect of the free conditions of the English speaking people in promoting Eternal Peace.

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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE, UNDER THE DIRECTION OF E. L. MARK, No. XC.

STUDIES ON THE CENTRAL AND PERIPHERAL NERVOUS SYSTEMS OF TWO POLYCHÆTE ANNELIDS.

By Margaret Lewis.

With Eight Plates.

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Presented by E. L. Mark, May 12, 1897.

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I. INTRODUCTION.

My study of the nervous system of certain annelids was begun in the summer of 1895 at Wood's Hole, at the suggestion of Prof. C. O. Whitman, who proposed that I should if possible ascertain the nature of the metamerism of Clymenella torquata, as expressed in its nervous system. This species proved to be poorly adapted to the elucidation of this question; but the investigation of the nervous system has been continued during my two years of study at Radcliffe College, under the direction of Professor Mark of Harvard University. The work undertaken at Wood's Hole was confined to Clymenella torquata, but the discovery of a new worm, Clymene producta, and the use of special methods of preservation, furnished me the material that first suggested an investigation of the so called giant fibres and giant cells. Sections of this worm killed in vom Rath's fluid gave me remarkably satisfactory preparations of many parts of the nervous system, especially of the giant cells and the sensory organs.

The two polychæte annelids with which this paper deals are members of the family Maldanidæ. One, Axiothea * (= Clymenella) torquata, is found in the sand flats of many regions of our New England coast. The other belongs to a different genus. It is a new species, which I found in one of the small harbors opening into Vineyard Sound. I have found it in only this one locality, although I have examined the sand flats of many parts of the shore. Its distribution would seem, therefore, much more limited than that of Axiothea torquata. In a recent description (Lewis, '97) of this new worm, I have proposed for it the name Clymene producta, the specific name having been chosen on account of the great length of the worm. It is sufficient here to state that this worm can be readily distinguished from Axiothea torquata by the much greater number of segments which it possesses, and by a series of red bands upon the anterior abdominal segments.

The nervous systems of these two worms, both the central system and the sense organs, present many interesting features, the description of which must be omitted from the present paper; such, for instance, as the eyes of the new species, and in case of both worms the ciliated grooves of the head.

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* As I have shown in a recent paper (Lewis, '97), there is not sufficient ground for retaining the generic name Clymenella, proposed by Verrill, since the worm described under that name clearly belongs to the genus Axiothea of Malmgren.

In spite of the great amount of productive work which has been done in recent years on nerve anatomy and histology, many of the prominent questions connected with nervous structures are still matters of dispute. The neuron theory, the question of the restriction of medullated nerve fibres to vertebrates, the nature and function of giant fibres in invertebrates, the relation of sense organs to nerve fibres, and, very recently, the presence and meaning of a centrosome in ganglionic cells, — all these are questions of a broad and fundamental nature, and every observation, however limited, which bears directly upon the solution of any of these questions is of value to those engaged in the study of nervous structures. A very few weeks of study upon the nervous system of the two annelids named demonstrated that they were peculiarly interesting in relation to some of these particular questions; for this reason my work has been restricted to observations bearing upon these questions of neurology.

II. CENTRAL NERVOUS SYSTEM.

The topics treated under the Central Nervous System fall naturally into two divisions, The Leydig's Fibres, and The Giant Cells. But for a correct understanding of these structures a short general account of the nervous system will be necessary.

1. General Topography.

a. *Location of Nervous System.*

The whole nervous system in these annelids seems to present a very rudimentary condition. With the exception of the brain, it lies in the hypodermis throughout the whole length of the animal. At no region except the brain is it found internal to the circular muscles. The ganglionic cells are always distinguishable from the adjacent cells of the hypodermis by their form and nuclei; but on the ventral side of the nerve cord there is no membrane nor other boundary separating them from the adjacent cells of the hypodermis (Plate **1**, Fig. 5, Plate **3**, Fig. 21). On the dorsal surface of the nerve cord, however, and on the dorsal parts of its lateral edges, such a boundary is present. The circular muscles on the dorsal side of the cord are everywhere strongly developed, and the lateral nerves pass off ventral to these muscles.

b. *Distribution of Ganglion Cells.*

There is no evidence of any strictly segmental arrangement of the parts of the central nervous system, either in the grouping of cells into ganglia, or in the relationships of the nerves given off from the ventral cord. Ganglionic cells are found abundantly throughout the length of the central nervous system, but, while more numerous in some regions than in others, they show no metameric plan of arrangement, nor any definite grouping into ganglia.

c. *Number and Distribution of Nerves.*

In each body segment lateral nerves are given off from the ventral cord in very large numbers. In some segments I have demonstrated more than thirty-five on each side of the body. The only feature of these nerves in any way suggestive of a metameric arrangement is their greater size in the region of the parapodia. These nerves are without a sheath, branch freely, and anastomose with one another, so that beneath the hypodermis there is a network of nerve fibres which forms an almost continuous sheet (Plate **1**, Fig. 4). Figures 66 and 67 (Plate **8**) are diagrams obtained by superimposing in each case a series of frontal sections of C. producta. Each shows the number and arrangement of nerves and giant cells in the anterior part of one segment. Figure 21 (Plate **3**) is a typical cross section of the nerve cord (from C. producta); it shows that the ganglionic cells occupy the ventral and lateral portions of the cord, and that on the dorsal side of the cord there is the cross section of what appears to be a tube. This is Leydig's fibre, which lies just ventral to the circular muscles.

In general, these facts point to an undifferentiated condition of the nervous system. Whether this condition is primitive, or has arisen secondarily, and therefore represents a degraded state of the nervous system, can of course be settled only by the aid of phylogenetic as well as ontogenetic evidence.

2. Methods.

My studies on the central nervous system of these annelids had to be pursued almost entirely upon sections of hardened material. Attempts to isolate the nerve cord were very unsatisfactory, because of the close intimacy of nervous system and hypodermis. Several methods of fixing and staining were employed, but of these the one given by vom Rath ('93, p. 102) proved to be pre-eminently valuable for the study of every part of the nervous system.

To prevent undue contraction it was found necessary to narcotize the worms thoroughly in all cases before killing. For the nervous system, owing to its situation in the hypodermis, partakes of all the folds of the body wall resulting from the contraction of the animal. A narcotizing mixture of about 5 volumes of 95% alcohol to 95 volumes of sea water gave the best results. A fuller account of the methods employed for studying different structures will be given under the separate topics.

3. Leydig's Fibres.

I have selected the name Leydig's fibre for a long known structure in annelids described under several different names; the principal ones, besides that which I have chosen, are neurochord, giant fibre, central canal, and neural canal. The name Leydig's fibre is adopted because Leydig was the first writer to give an accurate description of this structure; he also ascribes to it the nature which the most thorough and careful of recent investigations shows to be the most probable.

a. *Historical Review.*

These fibres have been studied by many writers, and the literature upon them is extensive. Bibliographical lists of considerable length, arranged chronologically, have been given by Spengel ('81, p. 41), Eisig ('87, p. 476), and Friedlaender ('89, p. 206; '94, p. 662).

But in spite of the fact that so much attention has been given to these structures, the most widely divergent conclusions have been drawn regarding their morphology and function, the latest papers upon the subject being no more harmonious than were the earlier ones. At least five different theories regarding the Leydig's fibres in annelids have been strongly urged.

First, that they are true nerve fibres of large size. This view was first set forth by Leydig in 1864, and it has been consistently supported by him in several subsequent papers. He declares these structures to be large medullated nerve fibres, — "riesige, dunkelrandige Nervenfasern," — and regards them as similar to the medullated nerve fibres of vertebrates. This theory received confirmation from Spengel ('81), who was the first to show that these fibres were the processes of ganglionic cells. Since, in the case of the annelid which he studied the number of longitudinal fibres remains tolerably constant and is much less than the number of giant cells, he believes that the larger fibres — "grösseren Röhren" — have arisen through the union of the direct processes of these ganglion cells.

Secondly, the view defended by Claparède (first in 1862, and several times subsequently), according to which these so called fibres have the nature of canals. While the various authors who use the terms canal or tube differ much in regard to the details of structure, they agree in the one notion, that Leydig's fibres are tubes. Most of the advocates of this view ascribe to these fibres no definite function.

Thirdly, that advanced by Kowalevsky ('71), which makes these structures supporting organs, homologous to the chorda dorsalis of vertebrates, and denies to them any nervous nature whatever.

Fourthly, the view advocated by Vejdovský ('84), which maintains the supporting nature of Leydig's fibres, but denies to them any genetic relationship to the chorda dorsalis of vertebrates. The relationship is one of analogy alone, since Leydig's fibres are derived from mesoderm, whereas the chorda dorsalis of vertebrates comes from entoderm. This view agrees with the third in denying all nervous nature to Leydig's fibres.

Fifthly, the idea advanced by Eisig ('87), which is that Leydig's fibres and the giant cells connected with them are in the young stages of the worm nervous in nature, but that later they undergo degeneration, and that the fibres finally come to function as a supporting organ. Thus they may in the adult worm be compared functionally with the chorda. He further suggests a comparison of these structures with the white matter of the nervous system of vertebrates, saying ('87, p. 483), "Auf Eine von mir schon im Vorhergehenden betonte Thatsache möchte ich aber bei dieser Frage nach der Bedeutung der Neurochordnerven noch einmal zurückkommen, weil sie möglicherweise mit zum besseren Verständnisse beitragen kann: ich meine die Thatsache, dass wir *im Nervensysteme der Anneliden fortan zwei Bestandtheile zu unterscheiden haben. Den einen bildete das dauernde, aus feinsten Fibrillen und zahlreichen kleinen Ganglienzellen sich aufbauende System, den anderen bildet das allmählich der Degeneration unterliegende, aus breiten Nervenfasern und wenigen riesigen Ganglienzellen zusammengesetzte.* Die Elemente des ersteren Bestandttheiles wurden in Anbetracht ihres histologischen Verhaltens öfters der 'grauen Substanz' der Vertebraten-Centren verglichen — vielleicht dürfen wir diejenigen des letzteren der 'weissen Substanz' gegenüberstellen."

Finally, there are those who deny to Leydig's fibres any nervous nature, on the ground that these fibres do not react to the Golgi method. These writers do not commit themselves to any definite statement as to the function of the structures in question.

The following lists give, in chronological order, the chief supporters of these various theories: —

1. Giant nerve fibres; truly nervous in nature.
   - '64, '64^a. Leydig.
   - '78. Schultze.
   - '80. Langerhans.
   - '81. Spengel.
   - '83. Vignal.
   - '83. Jacoby.
   - '86. Leydig.
   - '87. Rohde.
   - '88. Friedlaender.
   - '89–'91. Hatschek.
   - '89. Friedlaender.
   - '92. Cerfontaine.
   - '94. Friedlaender.
   - '95. Friedlaender.
2. Canal nature; axial canal or central canal.
   - '62. Claparède.
   - '62^a. Claparède.
   - '62. Keferstein.
   - '63. Clarapède.
   - '64–'68. Ehlers.
   - '68. Claparède.
   - '69^a. Claparède.
   - '73. Claparède.
   - '74. Greff.
   - '76. Semper.
   - '78. Vejdovský.
   - '78. McIntosh.
   - '79. Vejdovský.
   - '80. Spengel.
3. Homologous to chorda dorsalis of vertebrates.
   - '71. Kowalevsky.
   - '74. Semper.
   - '81. Perrier.
   - '85. Cunningham.
4. Analogous to chorda, but not related genetically.
   - '82. Vejdovský.
   - '83. Bülow.
5. Degenerate nerve fibres; the sheath or tube-wall retained as an organ of support.
   - '87. Eisig.
   - '88–'94. Lang (p. 221).
6. Not nervous in nature because they do not respond to the Golgi method.
   - '92. Von Lenhossék.
   - '92–92^a. Retzius.

The latest work, and the most conclusive of all, upon the Leydig's fibres, is that by Benedict Friedlaender. His observations and conclusions are based upon a very broad and complete series of investigations, — upon careful physiological experiments, as well as comparative morphological study. After investigating thoroughly both sheath and contents, his conclusion is, that Leydig's fibres are true nerve fibres arising from ganglionic cells, and further that they are *medullated* nerve fibres of the type found in vertebrates; that the sheath agrees in structure, at least in great part, with the myelin sheath of nerves in vertebrates, and that the contents represent the axis cylinder.

As his later papers are in full agreement with his earlier article of 1889, the words of the latter ('89, p. 258) may be quoted here: "Die sogenannte Neurochorde von Mastobranchus, Lumbricus und sehr wahrscheinlich die der Anneliden überhaupt, . . . endlich die markhaltigen Fasern der Wirbelthiere sind fundamental dieselben Gebilde."

b. *Methods employed.*

The present observations upon the fibres of Leydig were made upon sections only. These have been prepared from tissues fixed and stained by several methods. The reagent which proved most satisfactory for both contents and sheath was the picro-osmic-acetic-platinic chloride mixture of vom Rath ('95, p. 282), followed by wood vinegar. To obtain good preparations, it was very important to allow the material to remain for a long time in alcohol before embedding. Such preparations were valuable for tracing the courses of the cell-processes entering Leydig's fibres, as the sheath was stained black and therefore stood out prominently against the clear gray contents of the fibres and the surrounding nervous tissue. In preparations obtained by this method the course of the cell-processes in entering Leydig's fibre could be traced with low powers of the microscope. Other material, fixed in corrosive sublimate, alcohol, or formol, and stained with ordinary hæmatoxylin dyes or with iron hæmatoxylin, were used for comparison.

c. *Structure of Leydig's Fibres.*

Leydig's fibres from specimens of both C. producta and A. torquata, killed in the vom Rath mixture, differed considerably in the appearance of both the contents and the sheath from those prepared by other means. In sections of material prepared by the vom Rath method the sheath of the fibre was much more prominent than in those obtained by other methods. It appeared sometimes as a single wall with double contour, but more often gave the appearance of being composed of strands or lamellæ (Plate **2**, Figs. 15, 16). It becomes black by this treatment, and is readily distinguishable from the neuroglia, which stains brown, and also from all other parts of the nervous system. In this blackening with osmic acid it shows an agreement with the medullary sheath of the nerve fibres of vertebrates. On the other hand, in sections prepared from alcoholic or sublimate material, the sheath, if it could now be called such, was often inconspicuous, and in places seemed to be lacking entirely. Sometimes after such treatment it gave the appearance of strands or lamellæ, but it never exhibited the prominent condition which preparations of the vom Rath material showed. This changed appearance of the sheath I believe to be due to its having been partly dissolved by the alcohol, thus leaving in the sections only a part of the original sheath.

The contents of the fibre in most of the vom Rath material entirely filled the sheath, but occasionally they were slightly shrunken away from the wall. The contents were pale, clear, bluish gray in color, and presented a very delicate structure, which is uniform throughout the fibre. Leydig's fibre consists, therefore, of a single nerve fibre, not of a bundle of fibres. I have not been able to discover by any of the methods used anything in the contents of a fibrillar or striate nature. In a few cases it seemed as if the granules showed for a short distance a linear arrangement, but not such a condition as could properly be called fibrillar. In sections prepared by ordinary methods of fixing, these fibres often showed shrinkage; and such appearance might oftentimes lead to the conclusion which Eisig drew in the case of the Capitellidæ, viz. that the fibres showed evidence of degeneration.

It is clear, then, that the results here given regarding the finer structure of Leydig's fibres in the case of Clymene producta and Axiothea torquata agree in almost all respects with those of Friedlaender. The conclusions of the present paper are: —

1) Leydig's fibre is a tubular structure, consisting of wall and contents. The wall blackens intensely when treated with osmic acid, agreeing in this respect with the myelin sheath of the nerve fibres in vertebrates. In alcoholic preparations the sheath partially or entirely disappears.

2) The contents of the tube show an exceedingly fine and delicate structural condition, identical with that of the individual nerve processes of ganglionic cells. In sections prepared by the vom Rath method, they present the appearance shown in Figure 16 (Plate **2**). There is not the slightest evidence that Leydig's fibre is composed of a bundle of nerve fibrillæ.

d. *Relation to Cells.*

As far as regards the topographical relation of Leydig's fibres to the cells connected with them, these two Maldanidæ differ markedly from all other annelids in which these structures have been described.

In all the accounts which I have read of giant cells and connected giant fibres, the cells have been described as showing a metameric distribution. But in the cases of both C. producta and A. torquata, I find no evidence of a metameric arrangement of the giant cells. In both worms the cells which give rise to the giant fibres are situated without any discoverable regularity or symmetry along the sides of the nerve cord, and in a few instances ventral to it. The number of such cells varies in different segments. The giant cells of the two species correspond in position only in so far as there is no regular plan of distribution in either case. In both instances they present a well marked and characteristic cell-structure, which serves to distinguish them from the other cells of the nervous system. This structure will be described later, after a description and comparison of the courses of the fibres in the two species has been given.

The processes of the different giant cells, after a more or less irregular course, enter the Leydig's fibre, and immediately upon their union with it the individual processes lose their respective sheaths. The contents of the process, fusing with the contents of the Leydig's fibre, lose their identity. Such a connection of fibre and cells has been demonstrated in dozens of my preparations. Several times a single fortunate section has shown the connection of cell and fibre, but far more often the connection was established only by following through several successive sections. *A large number of absolute demonstrations in various parts of the worm leave no doubt that the Leydig's fibres are continually receiving the processes of certain large and peculiar cells,* occurring in very restricted number in the midst of the smaller cells of the nervous system (Plate **4**, Figs. 22, 23).

The Leydig's fibre is single and median in position through the whole thoracic region of both worms; but in the sub-œsophageal ganglion it divides into two symmetrical arms, which diverge and apparently end in a pair of symmetrically placed giant cells. I have not been able to determine with absolute certainty the nature of the anterior termination of these arms, for I have not ascertained whether the anterior end of Leydig's fibre always terminates in giant cells, or whether it may extend forward of the most anterior cell-processes with which I find it connected. My reason for believing that it terminates in a pair of giant cells is, that in the same section in which the most anterior part of the paired portion of the fibre is met with, or in sections very near to it, there is also found the anterior pair of giant cells. Sometimes these are clearly connected with the corresponding branches of the fibre, but the evidence on this point is not always satisfactory, and in some cases it seems possible that the branches of the fibre may end independently of the first giant cells.

In one important respect the results here presented regarding these cell-processes and Leydig's fibre differ from those of Friedlaender, viz. that no branching or anastomosing of the cell processes or of Leydig's fibre has been observed, and I believe that no such branching occurs.

e. *Comparison of the Course of Leydig's Fibres in the two Worms.*

In Clymene producta the conditions in the first twenty segments have been studied. Although the worm probably consists of more than seventy segments, the difficulty of obtaining entire worms has prevented such a study of the remaining segments as would give reliable topographical results. In these twenty segments I find the following conditions. Leydig's fibre appears in the sub-œsophageal ganglion as a pair of tubes which, passing caudad, very soon unite to form a single fibre extending backward along the mid-dorsal region of the nerve cord. It increases somewhat in diameter as it runs caudad, but the increase is slight in proportion to the size and number of the cell-processes which enter it. In this worm there is to be found in the first twenty segments only one Leydig's fibre.

In Axiothea torquata the fibre of Leydig consists in the sub-œsophageal ganglion of two tubes, precisely as in C. producta, as is shown by a series of cross sections of the worm through this region. These two tubes in passing caudad soon unite, thus producing a single fibre, which extends backward along the mid-dorsal region of the nerve cord as in C. producta. But this fibre continues single only as far as through the seventh segment. Beyond the seventh segment there are two fibres lying side by side almost in contact, and extending as far as the nineteenth segment. In the nineteenth segment the two again unite, and from this point onward there is again only one Leydig's fibre; this continues undivided, and ends in the twenty-second segment.

As long as Leydig's fibre remains a single structure, it shows the same relation to the giant cells as in the case of Clymene producta; but in the region where there are two fibres side by side, I find that some of the giant cells send their process into the fibre of the corresponding side of the cord, whereas the process of others crosses the median plane to enter the more remote fibre.

The two Leydig's fibres of Axiothea torquata extend throughout most of their course parallel to each other, lying side by side, but in certain places they cross each other. The crossing may be a single isolated one, or there may be two crossings in quick succession, so that an exchange of positions is quickly followed by a return of both to their original relations to the body. In these successive crossings, whether close together or far apart, a fibre, first passing above (dorsad of) its mate, may then pass back to the side on which it originally lay, either dorsad or ventrad of the other fibre. The first condition results in a simple crossing, the second in a real twisting of the fibres. In either crossing or twisting no anastomosing or branching of the two fibres has been discovered.

While the crossings of Leydig's fibres show in the different segments considerable variation in plan and number, there seems always to be at least one crossing near the parapodia; in no case have more than five crossings been found in a single segment. Thus it seems that in regions where two fibres exist side by side they show more evidence of metamerism than does the rest of the nervous system.

In the posterior segments of the worm it is difficult to obtain single sections that show any considerable length of Leydig's fibres. The whole nervous system follows the course of the epidermis, which in these segments is thrown into small folds or convolutions, whatever be the method employed in killing.

Attention may here be called to the fact, that in both these Maldanidæ the central nervous system lies external to the ring muscles, which serve as a mechanical support to it. In these cases, therefore, it is probable that Leydig's fibres do not themselves fulfil the same function.

f. *Function of Leydig's Fibres.*

That Leydig's fibres are truly nervous in nature is supported, first, by their direct connection with ganglion cells located in the midst of the central nervous system; secondly, by the finer structure of the fibre, both sheath and contents; and, thirdly, by the position of the fibres in the central nervous system.

The cells with which these fibres are connected certainly lie within the territory of the central nervous system, and are surrounded by other nerve cells. Their processes are traceable among the fibres of the ventral cord until they reach the Leydig's fibre. Such cells are found nowhere else in the animal except in the region of the nervous system. They show a marked resemblance in certain very important and peculiar details of their internal structure to the ganglionic cells described by von Lenhossék ('95ᵃ) for the central nervous system of the frog. These points of resemblance will be discussed later, when a detailed description of the cells is given.

It would seem as though the evidence that the cells in question are of a nervous nature was almost beyond question; but if this is so, then Leydig's fibres, which clearly are in direct continuity with the processes of the cells must likewise be of a nervous character. So far as I know, those writers who have themselves demonstrated the continuity of cells with Leydig's fibres have not denied the nervous nature of these structures. Only a very few of all the writers upon this subject, it is true, have actually shown such a connection. These authors are Spengel ('81), Rohde ('87), Haller ('89), Friedlaender ('89), and Cerfontaine ('92), all of whom are supporters of the nervous nature of Leydig's fibres.

Eisig, who believes that such continuity exists, although he did not actually demonstrate it, grants that the structures were originally nervous in nature, although in his opinion they have since become degenerate.

The ground upon which their nervous nature is denied by von Lenhossék and Retzius — viz. their failure to react to the Golgi method — seems very unimportant, especially when compared with the satisfactory work and positive results obtained by Cerfontaine with methylen blue. The capricious nature of the Golgi method is well known. It is granted by all workers who have employed this method that there are many nervous structures in any preparation which do not react to the silver process. Indeed, one of the things which makes a Golgi preparation especially valuable is the fact that only a small proportion of the nervous elements are affected by this treatment. Considering the exceedingly small number of Leydig's fibres in any preparation, and the limited number of workers who have employed the Golgi method upon them, it is not strange that no reaction has yet been obtained.

The evidence, however, is not yet sufficient to allow one to draw a safe conclusion as to the particular office of Leydig's fibres in the nervous economy of the worm.

g. *Bearing of the Condition of Leydig's Fibres in Annelids upon the Neuron Theory.*

The conditions of Leydig's fibres in Clymene producta and Axiothea torquata, as I have described them, and especially their relations to the great ganglion cells, have an important bearing on the recent neuron theory. We have here dozens of nerve cells sending their processes into the same nerve fibre. Immediately upon entering this fibre, these processes lose their respective sheaths, and to all appearances fuse with the contents of the fibre, thus losing their individuality. These facts are not easily reconciled with a theory which maintains that the relation of the processes of one nerve cell to those of another nerve cell is that of contiguity alone.

The neuron theory is now several years old, and it seems a little strange that when the generalization was extended to include the nervous system of invertebrates, no account was taken of the difficulty presented by Leydig's fibres, although the relation of such fibres to ganglionic cells had long been described. It was Waldeyer ('91) who first emphasized the principle of the nerve unit; and introduced the term "Neuron." He says (p. 52 of Separate): "Das Nervensystem besteht aus zahlreichen untereinander anatomisch wie genetisch nicht zusammenhängenden Nerveneinheiten (Neuronen)." Von Lenhossék ('95) declares the principle of the neuron to be true for invertebrates as well as vertebrates. He says ('95, p. 108): "Auch bei den wirbellosen Tieren setzt sich das Nervensystem aus Neuren zusammen." Later (p. 109) he says: "Nervenfaser, Terminalverästelung und Seitenzweige stellen leitende Medien, Auswüchse des Zellkörpers dar, die dieser dem Bedürfnisse entsprechend entwickelt, zu nahe und entfernt von ihm gelegenen Elementen Beziehungen einzugehen: andere Nervenzellen zu umspinnen, in sensible Endbezirke hineinzuragen oder sich an kontraktile Elemente anzulöten. Diese *Beziehungen bestehen stets in einem innigen Kontakt.* Darin liegt ein *wichtiges Organisationsgesetz,* nicht nur für die höheren Lebewesen, sondern auch für die wirbellosen Tiere, bis zu der Lebensstufe hinunter, wo die erste Nervenzelle und Nervenfaser in die Erscheinung tritt."

But in the case of Leydig's fibre, the entire weight of evidence is to the effect that we have direct continuity of substance, not simply intimate contact, between the processes of different nerve cells. I am aware that a zealous supporter of the neuron theory might claim that, although the individual cell-processes lost their respective sheaths on entering Leydig's fibre, still each process remained distinct and maintained its individuality, — that Leydig's fibre was simply a bundle of distinct nerve processes extending side by side, but closely pressed together. The evidence offered by the work of Cerfontaine ('92) with methylen blue is, however, entirely against such a supposition. Every worker with methylen blue as an *intra vitam* stain knows its tendency to pick out and stain a few nerve cells and nerve fibres. But the results obtained by Cerfontaine gave no evidence that parts of the fibre were selected by this stain and others left unstained, as would almost certainly be the case if it were composed of physiologically distinct strands or tracts. His figures show that Leydig's fibre, when treated with methylen blue, is a single homogeneous structure.

I regret that I have not had time and opportunity to experiment with the action of methylen blue upon these structures. But I believe that the facts already presented prove that there is no separation or boundary between these particular cell processes. But if there is no discoverable boundary, it is highly improbable that the processes retain their individuality and physiological independence. Leydig's fibre seems to be an effective means of bringing about an intermingling of the substance of these processes. The anastomosing of the different Leydig's fibres which Friedlaender and Cerfontaine describe in case of Lumbricus is another condition which harmonizes with this interpretation.

In view of these facts, we are led to believe that, whether or not the neuron theory holds true for vertebrates, it certainly does not apply to all invertebrates.

4. Giant Cells.

a. *General Account of Size, Number, Arrangement, etc.*

Under the name giant cells I include those large cells whose processes unite to form Leydig's fibre. In both worms the most anterior of these cells occupy the sub-œsophageal ganglion; and they are found in small numbers throughout the ventral cord. They are usually situated in the lateral portions of the nerve cord, but sometimes lie in the ventral part of it. They are not found in the brain. While in the larger number of cases the connection of these cells with the Leydig's fibre could not be shown in a single section, yet in several cases it has been possible to do this. It is not strange, in view of the frequently curved and irregular course of the cell-process, that such fortunate sections should be obtained only occasionally.

As has been stated before, these cells show no symmetry or regularity of arrangement, except in the region of the sub-œsophageal ganglion. In all the specimens examined, the giant cells of this region seemed to a certain extent to show a paired arrangement. In no other portion of the cord has anything approaching symmetry been found.

In neither species do the different segments of the worm show agreement in the number of these cells. By superimposing drawings of serial sections of two segments, I found the number of the cells in two successive segments of the nephridial region to be in one case twelve, in another eight.

The dimensions of the cells vary, and are in a measure proportional to the diameter of the worm, for they increase in size from its anterior end as far as that portion of the body in which the nephridia are found, this being the thickest part of the worm, and from this region onward they again diminish in size. The cells are also most numerous in the segments bearing nephridia, becoming scantier farther behind. But even in that part of the body where the cells are largest, they vary considerably in size. A comparison of several cells from the nephridial region gave a variation of from 30μ to 52μ in the long diameter, and of from 20μ to 40μ in the short diameter. Although showing this considerable variation in size, any of these cells are large enough to be easily distinguished from other cells of the nervous system, even by the use of very low powers of the microscope.

The giant cells are all unipolar. At least I have never found more than one nerve process, and I do not believe that more than one exists. In entering the fibre of Leydig the cell-process almost always takes a backward direction. Its course from the cell may be for some distance forward, but before entering the fibre of Leydig it is usually found to turn caudad (Plate **4**, Fig. 23). In a very few instances, in the posterior segments of Axiothea torquata, it has been seen to be directed cephalad as it entered the fibre.

The giant cells and their processes are surrounded by the same sort of a sheath as that which has been described for Leydig's fibre. It is evidently one continuous sheath extending around cell, cell-process, and Leydig's fibre. Around the cells it shows itself to be composed of several strands or lamellæ. The process from the giant cell shows an internal structure identical with that of Leydig's fibre, so that the account of the internal structure of the Leydig's fibre already given can be applied without change to the individual cell-processes. In sections which show the union of cell-process and Leydig's fibre there is, so far as the appearance of the contents of both go, no mark by which one could be distinguished from the other. Sections prepared from material treated with the vom Rath mixture show a delicate gray finely granular protoplasm which entirely fills the sheath (Plate **2**, Figs. 15 and 16) like that which has been described for the Leydig's fibre.

b. *Technique.*

The internal structure of the cell itself shows peculiar conditions, which are constant and equally well shown by two entirely different methods of fixation and staining; viz. (1) the vom Rath mixture already described, followed by wood vinegar, and (2) a cold saturated aqueous solution of corrosive sublimate followed by iron hæmatoxylin as a stain. The first method was in some respects the more satisfactory, since it seldom showed any shrinkage of the cell contents. But the iron-hæmatoxylin stain employed upon sections fixed with corrosive sublimate could be controlled more easily than the vom Rath preparations. The principal results regarding the internal structure of the cell obtained by one method were, however, fully confirmed by the other. It was very important in the use of the vom Rath mixture that there should not be too much osmic acid in the solution, and also that the material, after being treated with the wood vinegar, should remain for several days, or better weeks, in strong alcohol.

c. *Minute Structure.*

The giant cells are never spherical, their axes being of unequal length (Plate **1**, Figs. 1, 2, 3; Plate **2**, Figs. 8, 10, 13). Sections through the long axis of the cell are very unlike those through the short axes. In a section made parallel to the long axis, the nucleus is seen to occupy an eccentric position (Figs. 1, 2, 3), and is sometimes found lying in a sort of outpocketing of the cell (Plate **2**, Fig. 10). The nucleus, although large and distinct, is relatively much smaller than the nuclei of the smaller cells of the nerve cord (Plate **3**, Fig. 21), and has a well marked nuclear membrane. It usually contains only one large nucleolus, but sometimes two. The axes of the nucleus are frequently unequal, measurements of a dozen or more nuclei having given a variation from 11μ to 20μ for the long diameter, and from 8μ to 12μ for the short diameter. But sometimes the nucleus appears round, or nearly so, when cut in the long axis of the cell, — the direction which shows the inequality of the nuclear axes, if any exist. In sections perpendicular to the long axis of the cell the nucleus occupies a central position.

Near the nucleus, but nearer the centre of the cell, is a peculiar structure which seems as constantly present as the nucleus itself. In none of the giant cells prepared by either of the methods given was it ever wanting, although the details of the structure were not altogether uniform. The new species, Clymene producta, was much the more favorable of the two for the study of this structure, and all the giant cells figured are from that worm. No similar body has been mentioned for giant cells in other annelids, although the giant cells themselves have been described in the nervous system of annelids many times. An article by von Lenhossék ('95^a), which was received shortly after I first discovered these cells, describes for the nerve cells of the frog, under the name centrosome and sphere, a structure which resembled so strongly the peculiar body in the giant nerve cells of Clymene producta, that there could be no doubt of their being identical.

For the present, I shall designate the entire structure by the name "sphere," and later discuss the application of the term.

In the case of these giant nerve cells there could be made out in the sphere the following well marked regions. (Plate **1**, Figs. 2, 3; Plate **2**, Figs. 11, 12; Plate **4**, Figs. 24, 26; Plate **5**, Figs. 29–32.)

(1) The outer part of the differentiated region consists of a broad zone of rather coarse granules; (2) within this is a smaller central area of nearly homogeneous protoplasm; and (3) within this central area a

minute deeply staining body, or sometimes three or four such bodies. This corpuscle or group of corpuscles I call centrosome, employing von Lenhossék's term, although in the structure so designated there is a lack of agreement with von Lenhossék's centrosome, which will be pointed out later. There are radiations, which sometimes extend out beyond the sphere into the undifferentiated portions of the cell, but sometimes only through the coarsely granular zone of the sphere. In some preparations (Plate **1**, Fig. 2), these radiations traverse both zones, and seem to take their origin from the central corpuscle. In others (Plate **4**, Fig. 26), the radiations traverse only the outer more coarsely granular zone, and do not cross the inner more homogeneous area. The rays were usually present in rather small numbers, so that they could be readily counted. In such cases, they were generally separated by nearly uniform intervals, although often they were interrupted over an arc of many degrees. Occasionally the radiations were too numerous to be readily counted. In several preparations, they were so clear and strong that they could be seen without the use of anything higher than an E (Zeiss) objective, but in others they were brought out only by the use of an immersion lens. A ring of microsomes appeared in one preparation at a uniform distance from the central corpuscle (Plate **2**, Fig. 11).

The sphere was sometimes rather sharply marked off from the remaining protoplasm of the cell, but usually graduated into it.

In all the specimens of Clymene producta studied, there were found in the regions of the sub-œsophageal ganglion, and nowhere else, giant cells which contained each two spheres (Plate **2**, Figs. 8, 9, 13, 14). It was sometimes possible to make out in these cells a central corpuscle and radiations, but not with the same clearness as in many of the cells containing a single sphere. In most instances of cells containing two spheres, the spheres are very sharply marked off from the rest of the cell protoplasm, sometimes by a ring of granules, sometimes by a clear space around the sphere. It seems to me a peculiar fact that cells containing two spheres should always be found in this region and not in other parts of the worm; but I have no explanation of this fact to offer.

Outside the sphere the contents of these giant cells consist of a clear protoplasm, which appears identical with that of the cell-process and Leydig's fibre. In many cells there is at a little distance from the sphere a band of denser protoplasm, which partially surrounds the sphere, but is interrupted on the side toward the nucleus, apparently owing to the presence of that structure.

By the vom Rath method, as well as by the use of iron hæmatoxylin, the central corpuscle stains much more intensely than the surrounding zone. Occasionally it is slightly irregular in shape, and, as before stated, sometimes gives the appearance of a single body (Plate **1**, Fig. 2), but more often there seemed to be present several — two, three, or four — exceedingly small corpuscles (Plate **4**, Fig. 24).

Vacuoles resembling those described by Rohde and other writers sometimes occurred in the protoplasm close to the sheath surrounding the cell (Plate **1**, Fig. 3; Plate **4**, Fig. 25; Plate **5**, Fig. 29).

It is not difficult to trace a single giant cell through all the sections in which it is embraced, because this peculiar type of cell occurs so rarely in the nervous system that two such cells would seldom, perhaps never, occur so close together as to permit their being mistaken for each other.

d. Centrosome.

(1) *Historical Review.*

It is only recently that centrosomes were first recognized in nerve cells, and for that reason, if for no other, they have been mentioned by only a very few writers. So late as 1894, when Heidenhain wrote his paper, "Neue Untersuchungen über die Centralkörper und ihre Beziehungen zum Kern- und Zellenprotoplasma," such a structure was not known to exist in nerve cells. Heidenhain ('94, p. 656) merely suggests the possibility of its presence, for he closes his chapter regarding the universality of the centrosome with these words: "Kämen wir so zu positiven Resultaten, so würde es am Ende der van Beneden-Boverischen Theorie von der Ubiquität der Centralkörper am Ende nur einen geringen Eintrag thun, wenn sich schliesslich herausstellen sollte, dass es einige wenige Zellenformen giebt, welche, da sie im erwachsenen Thierkörper nicht mehr theilungsfähig sind, die Centralkörper völlig einbüssen. Es würde sich, soweit ich das zu beurtheilen vermag, wohl wesentlich nur um die Ganglienzellen handeln. Allein auch hier ist für eine Specialuntersuchung Aussicht auf Erfolg vorhanden, da doch von einigen Ganglienzellenformen her sowohl radiäre als auch concentrische Anordnungen bekannt sind."

Von Lenhossék ('95^{a}) was the first author positively to demonstrate the presence of a centrosome in ganglion cells. He describes very fully for certain of the spinal ganglion cells of the frog a well defined centrosome and sphere, and gives a detailed account of all the parts of the structure. As von Lenhossék was the first author to discover and describe this structure in nerve cells, I have preferred to make use of his terms "centrosome" and "sphere," although in some respects the conditions in the cells which I describe agree best with Heidenhain's "Microcenter" and "Centralkörper." Von Lenhossék employs Boveri's term "Centrosom" as a unit, designating by it a group of numerous very minute corpuscles held together by a "Zwischenmasse." He denies to each granule or corpuscle in the group the individual value which Heidenhain gives to each of his "Centralkörper." Von Lenhossék says ('95ª, p. 360): "Ich vermag die Beobachtungen Heidenhain's für mein Object vollauf zu bestätigen und möchte auf diese Zwischensubstanz besonderes Gewicht legen. Denn in ihrer Gegenwart erblicke ich dasjenige, wodurch das ganze Gebilde, mag es in seinem Innern noch so viele Körnchen beherbergen, doch immer in seiner Eigenschaft als *einheitlicher Körper* gewährleistet ist." And again (p. 361): "Somit könnte ich mich bei voller Anerkennung der Tragweite der Untersuchungen Flemming's und M. Heidenhain's der von diesen Forschern eingeführten Terminologie nicht anschliessen, bei der nicht das van Beneden-Boveri'sche Centrosom, sondern die darein eingebetteten *Körnchen* als Centralkörper benannt werden."

In none of the cells which I have studied do I find any such large number of minute granules held together by a "Zwischenmasse" as von Lenhossék describes. Often I have seen two, three, or four corpuscles in the centre of the sphere, but again, and more often, only one. This condition agrees better with the Microcenter and Centralkörper which Heidenhain describes.

The single central corpuscle, if only one is present, or the group of such corpuscles, if three or four are present, I call the centrosome. For the surrounding clear zone, the "Centralscheibe," described by von Lenhossék, it is best perhaps to employ his term "sphere," although the use of the term sphere for this structure is here open to the same objection as that which von Lenhossék urges: viz. it leaves out of account the coarsely granular zone, which he proposes to call the "Perisphere" or "Plasmasphere."

Dehler ('95) soon confirmed von Lenhossék's discovery. He found a similar condition in the sympathetic ganglion cells of the same animal, the frog.

Radiations from the region of the centrosome are neither described nor figured in the accounts given by either von Lenhossék or Dehler. The details of the "Centralkörpergruppe" figured by Dehler are much more nearly in agreement with the centrosome which I have described in this paper than is the centrosome of von Lenhossék. Dehler's "Centralkörpergruppe" agrees in its details with Heidenhain's Microcenter rather than with von Lenhossék's "Centrosom," although Dehler does not admit for each corpuscle the individuality and value which Heidenhain attaches to each Centralkörper. Rather, he would limit such a value to the entire "Centralkörpergruppe," thereby showing himself in agreement with von Lenhossék.

A word may here be said upon the methods employed by von Lenhossék and Dehler. Both attach great importance to the use of corrosive sublimate followed by iron hæmatoxylin for the demonstration of the centrosome, and both state that treatment with osmic acid gives unsatisfactory results. Dehler (p. 725) says: "Ich halte für das Studium des *feineren Baues* der Nervenzelle die Fixierung mit Osmiumsäurelösung und ihren Combinationen für weniger brauchbar, da sich die feineren Gebilde diffus, verschwommen, eventuell schichtweise ungleich färben." In regard to the use of osmic acid, my experience has been very different, since I obtained my last and clearest preparations from material prepared by vom Rath's ('93, p. 102) osmic mixture. After reading von Lenhossék's paper, I took pains to confirm my results by his method, — the use of corrosive sublimate followed by iron hæmatoxylin, — and the results, although offering an excellent confirmation of the preparations made with the vom Rath mixture, were in no respect better.

A short time before the publication of Dehler's paper, Buehler ('95) described "Centralkörper," in the sense of Heidenhain's term, found in cells from the cortex of the forebrain of the lizard, and also in nerve cells of the human brain. He says (p. 230, Separate, pp. 32, 33): "Demgemäss bin ich vollauf berechtigt zu erklären: *Die Centralkörper, wie sie Heidenhain in Leukocyten von Salamander und Kaninchen und in Riesenzellen des letzteren Tieres beschreibt*, dieselben Centralkörper, die auch Flemming vor ihm an ruhenden Leukocyten und Gewebszellen fand, die eine Reihe anderer Forscher in verschiedenen Zellformen in Ruhe, unter anderm ich selbst an den Samenzellen des Krötenhodens, gefunden haben, *diese Centralkörper finden sich auch in den Ganglienzellen der Vorderhirnrinde der erwachsenen geschlechtsreifen Eidechse.*"

Buehler also found radiations arising from the Centralkörper, or from the group of Centralkörper. This is the only instance, save in that of my previous paper (Lewis, '96), in which this significant feature has been described or figured. Buehler says (p. 227, Separate, p. 19): "Nicht selten finden wir Linien im Protoplasma, die annähernd radiär verlaufend von den Kügelchen aus nach der Peripherie der Zelle hinstreben."

Schaffer ('96) announces a similar discovery for another vertebrate type. He finds centrosomes in the "Schädelganglien von Petromyzon Planeri."

The first announcement of the presence of a centrosome in the nerve cells of an invertebrate was made by McClure ('96) for the unipolar ganglion cells of Helix. He gives no figures, but the brief description shows a condition corresponding in its principal features to the centrosome and sphere described by von Lenhossék.

When only von Lenhossék's and Dehler's papers had come into my hands, I gave my first account of the giant nerve cells of Clymene (Lewis, '96).* Further study has confirmed most of the statements made in that paper, and an opportunity for wider comparison with the statements of other writers strengthens the opinion then expressed, that this centrosome and sphere would be found to be of much more general occurrence in nerve cells than had hitherto been supposed.

Through the kindness of Mr. Hamaker of the Zoölogical Department of Harvard University, who has permitted me to see his preparations of the nervous system of Nereis, I am satisfied that he has demonstrated centrosomes in the giant cells of that annelid.

(2) *Function.*

Several facts suggest that this structure is a centre of mechanical activity in the cell: —

1) The concentric arrangement of the protoplasm around the centrosome.

2) The radiations which extend from the centrosome.

3) The strongly eccentric position of the nucleus.

4) The frequent flattening of the nuclear membrane on the side turned toward the centrosome.

5) The band of denser protoplasm partially surrounding the sphere, but interrupted by the nucleus.

I have no evidence that these cells undergo division, and it is pretty generally stated by authorities on nerve structures that ganglion cells after an early embryonic period never divide. Although I have sectioned and studied dozens of worms, I have never found the least indication of cell division in any cells of the nervous system of the adult.

As before stated, each of these giant cells has a single cell process.

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* [Although a copy of Buehler's paper had, through the courtesy of the author, reached me on Dec. 30, 1895, by some mischance it was overlooked, and did not come to the attention of Miss Lewis until her paper ('96) on "Centrosome and Sphere," etc. had been published. — E. L. Mark.]

The place of emergence of this process is not constant, but usually it seems to arise from the cell at a point between the centrosome and the nucleus. Figures 33, 33^a, 34 (Plate **5**) show the relation of cell-process to nucleus and centrosome in several cases.

The most important facts regarding the giant cells of the nervous system of these two worms may be summarized as follows: —

1) The giant cells give rise to Leydig's fibres.

2) They are present in very limited numbers throughout the nerve cord; they show no regularity of arrangement, and no constancy in number in the different segments.

3) They are all characterized by the possession of a nucleus, eccentric in position, and by the presence of a centrosome and sphere.

III. PERIPHERAL NERVOUS SYSTEM.

1. Introduction.

This part of the paper, dealing with the peripheral nervous system of the two Maldanidæ, Axiothea torquata and Clymene producta, was presented in substance before the American Morphological Society in December, 1896, and was afterwards summarized in Science, Vol. V. No. 115, p. 428.

Under the term "epidermal sense organs" I include certain organs found abundantly on all the segments of the body in both worms mentioned. Similar organs have been referred to in the case of the *head* and *proboscis* of certain marine annelids. One writer only, so far as I know, has mentioned such organs as being found on other parts of the body of any marine annelid. Eisig ('87, p. 547) has described similar organs from both the abdominal and thoracic segments of two of the Capitellidæ. No one has given any account of the plan of distribution of such organs, nor has their structure, as determined by the newer nerve methods, been described. I have examined the removed cuticula of four marine worms, representing three different families, and have found evidences of such organs in all parts of the integument of the worm; I conclude, therefore, that, if not universally present on the body of polychætes, they are at least very common in marine worms.

2. Methods Employed.

In Clymene and Axiothea, three principal methods of study were employed, the results obtained by one being confirmed and extended by the others. They were as follows: (1) maceration, by which the cuticula was removed entire for surface study; (2) sections, prepared either from material fixed in corrosive sublimate and stained with hæmatoxylin, or such as had been fixed in vom Rath's picro-osmic-acetic-platinic chloride mixture; (3) methylen blue employed upon living tissue, which was afterwards fixed, hardened, and sectioned.

For removing the cuticula the following procedure was found most successful. The worm was first narcotized in a mixture containing 95 volumes of sea water and 5 volumes of 95% alcohol, and then placed for a time, varying from 24 to 48 hours, in a 10% solution of sodium chloride. It was next removed to fresh water, and an incision through the cuticula of the back made with the points of scissors. The incision was carried along the whole dorsal line of the animal. A little shaking in the water with the forceps, aided with the scalpel, is sufficient to remove the cuticula entire, although it is usually most convenient first to cut the worms into pieces. The portions of cuticula thus obtained were floated upon slides; part of the water was drained off, and the rest allowed to evaporate. It is possible in this way to make permanent preparations of the cuticula. If the worm has been left in the salt solution a sufficient time, all the epidermal cells will remain behind, and a preparation of perfectly clean cuticula will be obtained. From such preparations the distribution of the sense organs could be determined easily by the use of low powers of the microscope. Preparations of this kind were also valuable for determining the presence and number of the canals serving for the passage of sensory hairs, and for comparing the sizes of the different sense organs.

Another method of maceration which was found fairly successful, although in general inferior to the one just described, was the use of a 1% solution of potassic bichromate. After the worm had been left in this solution for several weeks, fairly large pieces of cuticula could be removed.

For the study of the finer structure of the sense organs, material prepared by the vom Rath method gave the most satisfactory results. By this method, sense hairs and cuticula, as well as the cells of the epidermis, were well preserved. It was found to be important to use great care in narcotizing the worms before placing them in the killing fluid, for otherwise the sense organs are contracted so as to be worthless.

Sections from material fixed in mercuric chloride and stained with hæmatoxylin showed plainly the presence of the organs and the peculiar condition of the cuticula above them; but the sense hairs were matted together, and in other respects the preparations were inferior to those prepared by the vom Rath method.

After the presence of these sense organs had been established and their finer structure studied by the methods described, I was able to apply successfully the methylen blue method to living material. The results thus obtained confirmed what had already been found, and gave some additional facts. The methylen blue was used in the following manner. The worms were first narcotized with chloroform and then a 1.5% solution of methylen blue in normal salt solution (0.66%) was injected into the body cavity, the injection often being made in two or more regions of the body. The worm was then put back into sea water. After a few minutes a second injection, similar to the first, was made, and the worm was again returned to the sea water. In the course of five or six hours the sense organs gave evidence of being stained. The worms were then placed in Bethe's ('96) mixture for invertebrates to fix the blue, afterwards dehydrated in alcohol, embedded in paraffine, and cut into sections as thick as practicable. Grübler's B. X. brand of methylen blue proved to be the most satisfactory. The results obtained by the methylen blue method will be considered later. I will pass now to the consideration of the sense organs.

3. Distribution of Sense Organs.

Both Axiothea torquata and Clymene producta have two well marked body regions, separated from each other by a sort of collar. These two regions I call thoracic and abdominal, using the terms employed by Eisig for the body parts of the Capitellidæ. The distribution of the epidermal sense organs over these regions is as follows. (See Plate **8**, Fig. 68.)

a. *In the Thoracic Region.*

The thoracic region consists in both genera of the first four segments. The posterior part of the buccal segment and the anterior portion of the one next following show a peculiar mosaic arrangement of the surface not found in any other portion of the worm. The mosaic-like patches are bounded by irregular linear grooves, and their surface is slightly raised. Upon these patches the sense organs (represented in Fig. 68 by dots) are found in abundance. In the grooves both sense organs and gland pores are wanting. It is evident that the sense organs, being situated upon these patches, are more exposed to contact from without than they would be if they were located in the grooves.

The proboscis is longitudinally ribbed, and the sense organs upon it show a corresponding arrangement, for they are found upon the longitudinal ridges, not in the grooves.

Upon the crest of the head (see Lewis, '97, Plate **1**, Figs. 2 and 3) there are many sense organs of large size.

With the first setigerous segment (Plate **8**, Fig. 68) begins a well marked grouping of the sense organs, some 15 to 20 in number, posterior to and in the immediate vicinity of the ventral setæ. A similar grouping is shown in all the thoracic segments. At the anterior and posterior margins of the thoracic segments the sense organs are more numerous, forming ill defined circular bands, but in other portions of the segment they are rather uniformly distributed, though without any distinct plan.

b. *In the Abdominal Region.*

It is more difficult to study the sense organs in the abdominal region, on account of the extreme thinness of the cuticula; but by careful examination with high powers such organs can always be found. Toward the posterior extremity of the worm the cuticula again becomes thicker and the sense organs more prominent. The last segment of the tail ends in a funnel-shaped expansion within which numerous sense organs are found. Such a conspicuous grouping of sense organs as is seen in the thorax cannot be made out in the abdomen, although it seems evident that here too there is a slight concentration of organs around the setæ and at the anterior and posterior margins of the segments.

As a rule the sense organs vary in size directly with the thickness of the cuticula.

They resemble somewhat those described by various writers for Lumbricus, but differ from them in the following respects, at least: (1) no sheath cells are present; (2) gland pores are not absent from the region immediately surrounding them; and (3) the number of cells composing an organ is much smaller than in the case of Lumbricus.

4. Structure of Epidermis.

The epidermis of both these annelids shows three types of cells: (1) ordinary epidermal cells, (2) gland cells, which are very numerous in certain regions, and (3) the cells of the sense organs.

a. *Ordinary Epidermal Cells.*

The ordinary epidermal cells (Plate **7**, Figs. 63–65), the thread cells of certain writers, show great variation of form in different regions of the body. They are somewhat cylindrical, have an elongated nucleus and possess usually two or more thread-like roots, as long as the rest of the cell. The nucleus lies immediately above the point where the roots unite. In certain regions of the worm these cells are greatly elongated and very slender. Those shown in Figures 63–65 were stained in methylen blue.

b. *Gland Cells.*

The gland cells (Plate **3**, Figs. 17–20) are especially numerous in the fifth to the ninth segment of the body inclusive. They also show great variation in size and shape. The gland pore, situated at the free end of the cell, is readily seen in sections (Fig. 18) or in mounted specimens of removed cuticula (Fig. 19).

c. *Sense Organs.*

I propose to describe the sense organs somewhat minutely. Their appearance will be considered, first, in the removed cuticula; secondly, in sections prepared by ordinary methods and by the vom Rath fixative; and, thirdly, in methylen blue preparations. Conclusions as to their finer structure and their probable functions, and a historical review follow.

(1) *Cuticula.*

A study of the removed cuticula shows that it is everywhere made up of two systems of fibres, which cross each other at an angle of about 90° (Plate **3**, Fig. 19). Both systems are continuous, though faint, over each sense organ. The position of the sense organs is marked by a differentiation of the cuticula, which is nearly circular in outline. The cuticula of these areas is much reduced in thickness, but seems to be more highly refractive than the surrounding cuticula. No gland pores are present in these circular areas, but study with high powers reveals a number of very minute openings, — the canals through which the sense hairs pass. The number of these canals varies. I have counted as many as nine or ten in a single area. The diameter of the areas varies from 8μ to 16μ, and may even exceed this size. Frequently one or more cells from a sense organ are left hanging to the dried cuticula; in such cases the slender peripheral cell-process running up to the pore canal may be readily made out. Figure 19 (Plate **3**) is a camera drawing showing the appearance of the surface of a portion of the cuticula including one of these areas, made from the removed cuticula of Axiothea torquata. A section perpendicular to the surface of the body through one of the sense organs, from material fixed with the vom Rath fluid, is shown in each of the Figures 17 and 18 at the top of Plate **3**. From these, as well as from Figures 35–46 (Plate **6**) and 48–52 (Plate **7**), it is to be seen that immediately over the sense organs the cuticula is of less than half its usual thickness. It is deeply concave on the inner surface, and shows on the exterior a slight convexity, which is usually surrounded by a shallow circular depression.

(2) *Sensory Cells.*

After having given considerable attention to the matter, I have come to the conclusion that the sense organs of Clymene producta and Axiothea torquata are invariably composed of a number of spindle-shaped cells, — that there are no single or isolated sensory cells. The best general view of the sensory organ is obtained from sections perpendicular to the surface of the worm, made from material fixed in vom Rath's mixture, such as is shown, in part, in Figures 17 and 18 (Plate **3**). From sections of this kind it is to be seen that each sensory organ is composed of a small number — usually a dozen or less — of closely grouped spindle-shaped cells traceable through nearly the whole thickness of the epidermis. Near their basal ends these cells may take different directions, so that the bundle becomes dissolved before reaching the basement membrane. In such sections the exact shape of that portion of the sensory cell which lies next the cuticula could not be fully made out; but the grouping of the cells, the spindle-shaped body of each cell, and the sensory hairs passing through the cuticula, are all plainly visible. By no other method were the sense hairs so satisfactorily shown. Occasionally (Fig. 17) the cuticula is slightly pulled away from the cells of the sense organs, and in such cases the sensory hairs may remain in the cuticula, projecting beyond its free surface. Although the exact form of the peripheral portion of each cell could not be satisfactorily made out from such sections, yet enough could be seen to show that the cells are elongated and spindle-shaped, tapering both above and below the nucleus, which is oval, rather large, and contains a single nucleolus. Near the cuticula, the cells are closely pressed together, their peripheral ends being evidently very slender. In most cells the nucleus is situated at about half the height of the epidermis, but in some it may be near the cuticula and in others sunk to the base of the epidermis. This difference in the position of the nucleus is often shown in the different cells making up a single organ.

(3) *Results of Methylen Blue Method.*

The application of the methylen blue method confirmed the results obtained by other methods, and gave much additional information concerning the individual cells of the sense organs and their relation to nerve fibres. The results of the injection of methylen blue were studied both in the living tissue and in sections prepared after treatment by the ammonium-molybdate method of Bethe.

To study the living tissue of worms that had been injected with methylen blue, portions of the body wall in the head region were cut out, placed upon a slide, and observed under a cover glass after adding a few drops of sea water. The positions of the sense organs could be readily determined, but the thickness of the cuticula prevented any satisfactory conclusions as to the shape and number of the cells stained. Owing to the opacity of such preparations, the central processes of the cells could usually be followed only a very short distance. The sensory hairs often took the blue stain.

Two such hairs from an organ which had taken the blue stain were seen in one instance to move for a considerable time, and their position with reference to each other was seen to change. This was so strange a phenomenon, that I asked a friend to examine the living preparation at the time, and he confirmed my conclusion. So far as I know, however, there exists no observation to show that sensory hairs are ever capable of independent motion.

The results obtained from *sections* of the methylen blue material were far more complete and instructive. A comparative study of many sections was necessary, however, to give a satisfactory idea of a sense organ.

Often but one of the cells of the group making up an organ took the methylen blue stain, and from such preparations the hasty conclusion might have been drawn that only single isolated sense cells were under examination. A careful examination of the cuticula, however, almost always showed the presence of a concave inner edge and the doubly curved outer edge characteristic of the cuticula of a sense organ composed of several cells. In the very few cases in which this condition of the cuticula did not appear, there seemed reason to believe its absence due to a slight obliquity of the section.

Sometimes the blue of the stain was concentrated upon the concave inner surface of the cuticula covering the sense organ. In this way the presence of several separate organs could be recognized, all other portions of the cuticula remaining uncolored.

In other instances, all or nearly all the cells of an organ would be stained; in such cases little could be made out from the thick section, owing to the closeness of the opaque cells.

The most satisfactory conditions were perhaps those (Plate 6, Figs. 37, 38, 42–44, 47) in which only two or three of the cells of an organ had taken the stain, and that not too intensely, thus allowing the two poles of the cells to be traced, — the peripheral pole through, or partly through, the cuticula, the central pole for some distance toward the central nervous system.

(4) *Conclusions as to Finer Structure of Sense Organs.*

From the study of a large number of preparations made by the different methods described, I have reached these conclusions.

(1) That epidermal sense organs composed of a number of sense cells are present in all parts of the integument of the Maldanids, Clymene producta and Axiothea torquata, and that in certain regions of the worm these sense organs show a definite arrangement into groups and zones.

(2) That the cells of these sense organs are elongated, spindle-shaped cells, — bipolar nerve cells of the type described by Retzius ('92, '92^a, and '95) for the isolated sense cells of Nereis.

(3) That these bipolar cells differ much in the distance of the nucleus from the cuticula.

(4) That there are a considerable number of such bipolar cells in each sense organ, although in many cases only one cell takes the stain. In almost all cases in which only one cell is stained, the peculiar contours of the cuticula in sections give satisfactory evidence of the presence of a multicellular sense organ.

(5) That each of these cells possesses at its exterior end a sense hair. These hairs I believe capable of retraction below the cuticula, although I cannot offer conclusive evidence upon this point.

(6) That the deep portion of each of these cells is much more slender than the peripheral portion, and turns at an angle beneath the epidermis toward the central nervous system. But not all the processes from the central ends of the cells of an organ pass in the same direction. I have seen them in some instances separate when near the base of the epidermis, and diverge until they took opposite directions (Plate 6, Fig. 42), in which they could be followed for some distance. This would seem to indicate that nerve fibres from the same sense organ may enter the central nervous system from opposite sides. The exact manner in which the nerve fibres from these sensory cells enter the central nervous system I have not been able to observe.

(7) That the direction of the cells of the sense organs in reference to the cuticula varies considerably. As a rule, the long axis of the cell body is nearly perpendicular to the cuticula, and to the circular muscles.

But many cells show an oblique direction of the long axis with reference to the cuticula (see Plate **6**, Fig. 38, and Plate **7**, Fig. 51). It is evident that ordinary methods of staining would be very unsatisfactory for the discovery of these oblique cells.

(8) That in many respects the sensory cells of these epidermal sense organs show a remarkable resemblance to those described by Retzius ('92, '92^a, and '95) for Nereis. The chief point of difference is, that Retzius found *isolated* sensory cells in the case of Nereis, whereas in the case of these Maldanids the sense cells are grouped into definite sense organs. Is it not possible that the conditions seen and figured by Retzius may be accounted for without concluding, as Retzius has done, that sensory cells exist in the epidermis of Nereis as isolated single-cell organs? Is it not possible that Retzius, through failure to control his observations by sections made after the more ordinary methods of treatment, overlooked the fact that such apparently isolated cells really belonged to a multicellular sense organ?

(9) That the epidermal sense organs here described can be observed in the living worm into which methylen blue has been injected, the worm being placed in a shallow dish of sea water, and examined even under a comparatively low power of the microscope.

(5) *Function of Sense Organs.*

Regarding the function of these sense organs, I have little to suggest save of a negative character.

The fact that they are found at all parts of the surface of a worm inhabiting a tube would seem to be against the supposition that they are organs of taste. In such a worm organs of taste would be of little service except at the anterior region of the body. The same argument may be made against the supposition that they are organs of smell.

Certain facts seem to favor the supposition that they are tactile organs. That the worm is sensitive, even in the posterior region of the body, is shown by pinching or pricking the tail as it projects from the sand tube which it inhabits. Again, we find the organs especially numerous upon exposed or elevated parts of the body.

Spengel, who found similar organs, but only in the mouth region of certain marine annelids, held them to be organs of taste on account of their position in the mouth; but this reasoning could not hold for organs found in other regions of the body. It is not impossible, of course, that in the region of the mouth such organs function as organs of taste, and in other parts of the body as tactile organs.

(6) *Historical Review.*

In going over the literature concerning epidermal sense organs in annelids, I have found that only a very few of the writers upon polychætes have made any reference to such organs as those which I have described, and in no case have I found any account of the finer structure of those organs which agrees with the results that I have obtained. I shall refer in chronological order to the writings of such authors as seem to have had under investigation organs similar to those of Axiothea and Clymene.

Claparède ('68), in his account of Nepthys scolopendroides, describes in a general way, under the head "papilles de la trompe," structures which may possibly be the same as the epidermal sense organs of these Maldanidæ. He says (p. 487): "Les papilles qui bordent l'ouverture de la trompe portent des terminaisons nerveuses, très-remarquables, qui font défaut aux cercles de papilles plus extréieurs. Ces papilles sont triangulaires et de deux espèces: les unes larges et les autres minces. Ces deux formes alternent régulièrement l'une avec l'autre. La première seule porte les organes en question, sous la forme d'une véritable forêt de longues soies délicates, ondulées, fort ténues. Elle sont situées à la base de la papille. Quelques faisceaux de nombreuses soies semblables se voient encore vers le milieu de la papille. En revanche, le sommet de celle-ci en est dépourvu et ne présente que quelques petites éminences striées à peine appréciables, rappelant les organes tactiles des palpes des Néréides. Les soies que je viens de décrire ne sont reconnaissables qu'à l'aide de forts objectifs. La question de savoir si ce sont des éléments nerveux est sans doute indécise. Le nerf de chaque papille s'épanouit en un pinceau dont les fibres viennent aboutir sous la cuticule fort amincie. Il est par suite facile de supposer une continuité entre les fibres et les soies ondulées de la surface. Toutefois, je reconnais que cette continuité ne peut guère être un fait d'observation."

Spengel ('81), describing the folds of the proboscis in certain polychæte annelids, says (p. 21): "Kaum minder stark entwickelt als bei Lumbriconereis sind solche Falten bei Arabella und namentlich bei Halla. Bei letzterer Gattung sind sie der Sitz wohl ausgebildeter 'becherförmiger Organe,' die empfehlenswerthe Objecte zum genauren Studium dieser so weit verbreiteten Form des Sinnesepithels sein dürften. Die Anordnung derselben erhellt aus Fig. 32, was ich von ihrer Structur erkannt habe, aus Fig. 33. Dieselben sind dadurch ausgezeichnet, dass sie von einer dicken, hellen, aber von feinen Poren durchbrochenen Cuticula bedeckt sind; dass diese Poren zum Durchtritte von Sinneshaaren dienen werden, ist in hohem Grade wahrscheinlich, liess sich indessen an den conservirten Thieren nicht mehr nachweisen. Die Sinnesorgane selbst sind aus hellen, mit einem länglichen Kerne etwas unterhalb ihrer Mitte versehenen Cylinderzellen gebildet, die einen etwa kugligen Körper darstellen. Die Lage lässt in denselben Geschmachsorgane vermuthen. Auch bei Lumbriconereis sind ähnliche Sinnesorgane vorhanden, doch minder scharf differenzirt." It is probable that the structures which Spengel describes are similar to those described in the present paper.

Eisig ('87) describes in his monograph of the Capitellidæ, under the name "becherförmige Organe," structures which are undoubtedly equivalent to the sense organs of the Maldanids here described. He states that they are found on the head, proboscis, and thorax of all the Capitellidæ, and in case of two species of the family, besides being found in these regions, they are also present on the abdomen. No other author has, so far as I know, mentioned such organs in case of polychætes for any region except the proboscis. Regarding their distribution, Eisig says (p. 547): "Im Gegensatze zu den streng metamerangeordneten Seitenorganen zeigen die becherförmigen Organe eine von der Körpersegmentirung durchaus unabhängige, also *diffuse Vertheilung*." And concerning their structure he adds (p. 547): "Was die Structur der becherförmigen Organe betrifft, so sind auch bei ihnen als auffallendste Theile die auf den Hügelkuppen concentrirten, frei in das Medium hinausragenden Sinneshaare hervorzuheben. Diese Haare sind etwa 4μ lang, wenig zahlreich und überall gleich breit, also stäbchenförmig. So wie bei den Seitenorganen durchsetzen sie die die Hügel überziehende Cuticula, um in ein Bündel central gelegener, langgestreckter Sinneszellen überzugehen. In letzteren Sinneszellen erkennt man ohne Weiteres den Typus der Hautfadenzellen wieder."

In regard to the innervation of these "becherförmige Organe," Eisig gives the following (p. 548): "Meine bezüglichen Nachforschungen hatten denn auch keinerlei derartiges Resultat zur Folge, so dass wir wohl annehmen müssen, dass die Sinneszellen der Becherorgane ebenso wie die Fadenzellen der Haut von dem integumentalen Ganglienzellenplexus aus mit Nervenfibrillen versorgt werden."

It is evident that Eisig's results concerning the finer structure of these sense organs, i. e. concerning the form of the sensory cells and their innervation, have not much in common with the results which have been given in this paper. The fact that none of the finer methods of nerve technique were employed by the authors hitherto quoted probably accounts adequately for the points of difference between their conclusions and mine.

I come now to the consideration of the work which has been done upon the sense organs of polychæte annelids by means of the newer nerve methods. Retzius, working both with the Golgi method and with methylen blue in 1892, and confirming in 1895 his previous work, describes for the epidermis of Nereis certain *isolated* sensory cells, which in almost all the details of their structure and in their variations of form and position show a remarkable resemblance to the cells of the sense organs which I have described. I, however, have never found the cell body and nucleus sunk beneath the deep ends of the epidermal cells into the underlying tissue, as Retzius has. I find some of the nuclei of the sensory cells, it is true, at the most variable distances beneath the cuticula, even as deep as the base of the epidermis, where they may lie immediately above the circular muscles, either in an oblique position or parallel with those muscles, and it not infrequently happens that such a nucleus is situated at some distance from the vertical axis of the sense organ to which it belongs.

For this apparent difference of condition between Nereis and the Maldanidæ, there are three possible explanations: —

(1) The Maldanidæ studied by me may have had in the epidermis isolated sense cells which did not respond to the blue method and were consequently overlooked; and on the other hand Nereis may have contained sense organs similar to those of the Maldanidæ, which did not respond to the methods employed by Retzius.

(2) As Retzius used in his work only the Golgi and the methylen blue methods, neither of which are especially favorable for the preservation of the outline of the cuticula above the sense organs, he may have overlooked any such indication of multicellular sense organs. Moreover, since frequently only a single cell from such an organ stains with the blue, he may have seen only such conditions and have consequently interpreted them as isolated sense cells.

(3) The epidermis of Nereis may differ so much from that of these Maldanidæ as to have only isolated sense cells, while the Maldanidæ have sense cells grouped into sense organs. This third supposition, however, I think unwarranted. For although I have studied Nereis by means of the removed cuticula only, I am convinced from the examination of this cuticula that organs resembling those which I have described for the Maldanidæ are likewise present in their integument.*

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* Since this part of the present paper was completed, the report of the meeting of the American Morphological Society for December, 1896, has been received

Before concluding this paper I would take the opportunity to express my sincere gratitude to the director of my studies, Professor E. L. Mark, for the assistance and advice which I have constantly received from him. And I would gratefully acknowledge my indebtedness to the officials of Radcliffe College for the encouragement which they have given me in my work, and to the Society of Collegiate Alumnæ for the aid I have received from them in the form of a fellowship.

IV. SUMMARY.

1. Confirmation of the view that Leydig's fibres in annelids are true nerve fibres; that the sheath of Leydig's fibre is comparable to the medullary sheath of nerve fibres in vertebrates; that the contents are comparable to the axis cylinder; and hence, as has been pointed out by Friedlaender, that the line which has been drawn between the nerve fibres of vertebrates and invertebrates cannot be maintained.

2. Confirmation for Maldanidæ of the theory that Leydig's fibres do not function in any way as an organ of support. They are neither homologous nor analogous to the chorda dorsalis of vertebrates.

3. Confirmation of the view that Leydig's fibres result from the union of the direct processes of giant ganglion cells. In Axiothea torquata and Clymene producta these cells appear in the sub-œsophageal ganglion, and are found scattered along the lateral and ventral portions of the

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(Science, Vol. V. No. 115, March 12, pp. 423–436). This report contains (pp. 427, 428) an abstract of a paper by Miss F. E. Langdon on "The Peripheral Nervous System of Nereis virens." The writer says: "The spindle-shaped sensory cells described by Retzius as isolated are really grouped into semi-organs, which have a definite distribution over the body. Each organ consists of a fusiform group of cells, whose bodies lie below the epidermis or in its base. The cuticular markings over the organs in the appendages of the body are like those over the sense organs of Lumbricus. Over the body itself each cuticular marking is concave on the exterior, and the very thick cuticula encloses beneath each marking an ovoid cavity, through which pass the outer ends of the sensory cells. Each sensory cell usually bears several sensory hairs, and these hairs cannot be retracted normally as supposed by Retzius."

There is one noteworthy difference between this description and that which I have given for the epidermal sense organs of the Maldanidæ. I have found *only a single sensory hair to each sense cell* in case of the Maldanidæ studied, whereas Miss Langdon has found that in the case of Nereis *each sensory cell usually bears several sensory hairs.* We are, however, in agreement as to the grouping of the sensory cells into multicellular organs.

nerve cord without indicating metamerism or symmetry. In the subœsophageal ganglion, however, they show an approach to symmetry.

4. Confirmation of the conclusion that the substance of Leydig's fibre is uniform throughout and does not represent a bundle of nerve fibrillæ; further, that the fibre does not show any indication of being a degenerate structure.

5. In their relation to ganglion cells, Leydig's fibres, if real nerve fibres, as maintained, stand in strong opposition to the neuron theory of Waldeyer, von Lenhossék, Edinger, and other writers. The relation of the process of one giant cell with that of another appears to be one of direct continuity, not simply of contiguity.

6. The cells which give rise to Leydig's fibres show peculiar structural conditions in the possession of a nucleus always eccentric in position and in the possession of other structures more central in position, the centrosome and sphere.

7. The presence of a centrosome in these ganglion cells argues for a function of the centrosome other than that of an organ for cell division.* No division of nerve cells has been observed in this worm, and, besides, cell division is generally believed never to occur in case of normal ganglion cells.

8. Although not an organ of cell division, the centrosome in these ganglion cells is evidently a centre of mechanical activity. This is indicated, (*a*) by the eccentric position of the nucleus; (*b*) by the flattening or indentation of the nuclear membrane, frequently observed on the side toward the centrosome; (*c*) by the concentric arrangement of the protoplasm around the centrosome; and (*d*) by the radiations which extend from the centrosome.

9. The presence of a centrosome in ganglionic cells is an argument in favor of its being a permanent cell organ.

10. In some of the giant cells two centrosomes and spheres are present, without there being any evidence of approaching nuclear division.

11. Parts of the peripheral nervous systems of the two Maldanidæ, Axiothea torquata and Clymene producta, terminate in multicellular

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[* The identity of the centrosome here described with that which usually accompanies cell division is here assumed; but it has not been proved. An important problem for the future is to determine if a genetic connection can be established between this so called centrosome of nerve (and other) cells and the centrosome which exists during cell division. — E. L. MARK.]

sense organs occurring abundantly throughout the integument of both worms.

12. These sense organs show in certain regions of the body a definite plan of distribution, being collected into rows, groups, and zones.

13. Isolated sense cells are not present in the epidermis.

14. The individual cells which make up the sense organs are bipolar nerve cells, resembling the isolated sense cells which Retzius described for the epidermis of Nereis. The peripheral prolongation of each cell carries at its free end a single sensory hair; the prolongation of the deep end has not been completely followed out, but as far as traced is unbranched, and represents a nerve fibril.

BIBLIOGRAPHY.

Beddard, F. E.

'83. On the Anatomy and Histology of Pleurochæta Mosleyi. Trans. R. Soc. Edinburgh, Vol. 30, Part 2, pp. 481-509, Pls. 25-27.

Bethe, A.

'96. Eine neue Methode der Methylenblaufixation. Anat. Anz., Bd. 12, No. 18, pp. 438-446.

Buehler, A.

'95. Protoplasma-Structur in Vorderhirnzellen der Eidechse. Verhandl. phys.-med. Gesellsch. zu Würzburg, N. F., Bd. 29, No. 6, pp. 209-252, Taf. 3-5.

Also separate, 44 pp., 3 Taf., 1895.

Bülow, C.

'83. Die Keimschichten des wachsenden Schwanzendes von Lumbriculus variegatus nebst Beiträgen zur Anatomie und Histologie dieses Wurmes. Zeit. f. wiss. Zool., Bd. 39, Heft 1, pp. 64-96, Taf. 5.

Cerfontaine, P.

'90. Recherches sur le système cutané et sur le système musculaire du Lombric terrestre (Lumbricus agricola Hoffmeister). Arch. de Biol., Tome 10, pp. 327-428, Pls. 11-14.

Cerfontaine, P.

'92. Contribution à l'étude du système nerveux central du Lombric terrestre. Bull. Acad. roy. Belgique, 3me Série, Tome 23, pp. 742-752, Pls. 1, 2.

Claparède, E.

'62. Études anatomiques sur les Annélides, Turbellariés, Opalines et Grégarines observés dans les Hébrides. Mém. Soc. Phys. et Hist. nat. Genève, Tome 16, pp. 15-165, 7 Pls.

Also separate, Genève, 1861, 96 pp., 7 Pls.

Claparède, E.

'62a. Recherches anatomiques sur les Oligochètes. Mém. Soc. Phys. et Hist. nat. Genève, Tome 16, pp. 217-291, 4 Pls.

Also separate, Genève, 1862. 75 pp., 4 Pls.

Claparède, E.

'63. Beobachtungen über Anatomie und Entwicklungsgeschichte wirbelloser Thiere an der Küste von Normandie angestellt. Leipzig, viii + 120 pp., 18 Pls., folio.

Claparède, E.

'68. Les Annélides chétopodes du Golfe de Naples. [1e partie.] Mém. Soc. Phys. et Hist. nat. Genève, Tome 19, pp. 313-584, Pls. 1-16.

Claparède, E.
'69. Les Annélides chétopodes du Golfe de Naples. 2e partie. Mém. Soc. Phys. et Hist. nat. Genève, Tome 20, pp. 1–223, Pls. 17–31.

Claparède, E.
'69a. Histologische Untersuchungen über den Regenwurm (Lumbricus terrestris Linné). Zeit. f. wiss. Zool., Bd. 19, Heft 4, pp. 563–624, Taf. 43–48.

Claparède, E.
'73. Recherches sur la structure des Annélides sédentaires. Mém. Soc. Phys. et Hist. nat. Genève, Tome 22, pp. 1–199, Pls. 1–15.

Cunningham, J. T.
'85. The Significance of Kupffer's Vesicle, with Remarks on other Questions of Vertebrate Morphology. Quart. Jour. Micr. Sci., Vol. 25, No. 97, N. S., pp. 1–14, Pl. 1.

Dehler, A.
'95. Beitrag zur Kenntnis vom feineren Bau der sympathischen Ganglienzelle des Frosches. Arch. f. mikr. Anat., Bd. 46, Heft 4, pp. 724–743, Taf. 38.

Ehlers, E.
'64–68. Die Borstenwürmer (Annelida chætopoda) nach systematischen und anatomischen Untersuchungen dargestellt. Leipzig, Engelmann, xx + 748 pp., 24 Taf.

Eisig, H.
'87. Monographie der Capitelliden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte nebst Untersuchungen zur vergleichenden Anatomie und Physiologie. Fauna u. Flora des Golfes von Neapel. Monographie XVI., Berlin, xxvi + 906 pp., 37 Taf.

Emery, C.
'86. La régénération des segments postérieurs du corps chez quelques Annélides polychètes. Arch. Ital. Biol., Tome 7, pp. 395–403.

Friedlaender, B.
'88. Beiträge zur Kenntnis des Centralnervensystems von Lumbricus. Zeit. f. wiss. Zool., Bd. 47, Heft 1, pp. 47–84, Taf. 9, 10.

Friedlaender, B.
'89. Ueber die markhaltigen Nervenfasern und Neurochorde der Crustaceen und Anneliden. Mitth. Zool. Stat. Neapel, Bd. 9, Heft 2, pp. 205–265, Taf. 8.

Friedlaender, B.
'94. Altes und Neues zur Histologie des Bauchstranges des Regenwurms. Zeit. f. wiss. Zool., Bd. 58, Heft 4, pp. 661–693, Taf. 40.

Friedlaender, B.
'95. Ueber die Regeneration herausgeschnittener Theile des Centralnervensystems von Regenwürmern. Zeit. f. wiss. Zool., Bd. 60, Heft 2, pp. 249–283, Taf. 13, 14.

Greeff, R.
'74. Ueber die Organisation der Echiuriden. Sitzb. Gesell. z. Bef. ges. Naturw. Marburg, Jahrg. 1874, No. 2, pp. 21–30.

Haller, B.
'89. Beiträge zur Kenntniss der Textur des Central-Nervensystems höherer Würmer. Arbeit. Zool. Inst. Wien, Tome. 8, Heft 2, pp. 175–312, Taf. 16–20.

Hatschek, B.
'89–'91. Lehrbuch der Zoologie, u. s. w. Lieferungen 1–3. Jena, G. Fischer. 432 pp. [unfinished].

Heidenhain, M.
'94. Neue Untersuchungen über die Centralkörper und ihre Beziehungen zum Kern- und Zellen-protoplasma. Arch. f. mikr. Anat., Bd. 43, Heft 3, pp. 423–758, Taf. 25–31.

Jacobi, R.
'83. Anatomisch-histologische Untersuchung der Polydoren der Kieler Bucht. Inaugural-Dissert. phil. Facultät zu Kiel. Weisenfels, Leopold Kell, 35 pp., 2 Taf.

Keferstein, W.
'62. Untersuchungen über niedere Seethiere. Zeit. f. wiss. Zool., Bd. 12, Heft 1, pp. 1–147, Taf. 1–11.

Kowalevsky, A.
'71. Embryologische Studien an Würmern und Arthropoden. Mém. Acad. Sci. St. Pétersbourg, sér. 7, Tome 16, No. 12, 70 pp., 12 Taf.

Lang, A.
'88–'94. Lehrbuch der vergleichenden Anatomie der wirbellosen Thiere. Jena, G. Fischer, 1888–94, xvi + 1198 pp., 251 Abbildg.

Langerhans, P.
'80. Die Wurmfauna von Madeira. III. Zeit. f. wiss. Zool., Bd. 34, Heft 1, pp. 87–143, Taf. 4–6.

Lenhossék, M. von.
'92. Ursprung, Verlauf und Endigung der sensibeln Nervenfasern bei Lumbricus. Arch. f. mikr. Anat., Bd. 39, Heft 1, pp. 102–136, Taf. 5.

Lenhossék, M. von.
'95. Der feinere Bau des Nervensystems im Lichte neuester Forschungen. 2 Aufl. Berlin, vii + 409 pp., 6 Taf. u. 60 Textfiguren.

Lenhossék, M. von.
'95^a. Centrosom und Sphäre in den Spinalganglienzellen des Frosches. Arch. f. mikr. Anat., Bd. 46, Heft 2, pp. 345–369, Taf. 15, 16.

Lewis, M.
'96. Centrosome and Sphere in Certain of the Nerve Cells of an Invertebrate. Anat. Anzeiger, Bd. 12, No. 12, 13, pp. 291–299, 11 Figs. Sept. 2.

Lewis, M.
'97. Clymene producta sp. nov. Proc. Bost. Soc. Nat. Hist., Vol. 28, No. 5, pp. 111–115, 2 Pls. August.

Leydig, F.
'64. Vom Bau des thierischen Körpers. Handbuch der vergleichenden Anatomie, Bd. 1, Haelfte 1, Tübingen, vii + 278 pp.

Leydig, F.
'64^a. Tafeln zur vergleichenden Anatomie, Heft 1. Zum Nervensystem und den Sinnesorganen der Würmer und Gliederfüssler. Tübingen, 10 Taf., 24 pp.

Leydig, F.
'86. Die riesigen Nervenröhren im Bauchmark der Ringelwürmer. Zool. Anzeiger, Jahrg. 9, No. 234, pp. 591–597.

McClure, C. F. W.
'96. On the Presence of Centrosomes and Attraction Spheres in the Ganglion Cells of Helix Pomatia, with Remarks upon the Structure of the Cell Body. Princeton Coll. Bull., Vol. 8, No. 2, pp. 38–41.

McIntosh, W. C.
'78. Beiträge zur Anatomie von Magelona. Zeit. f. wiss. Zool., Bd. 31, Heft 4, pp. 401–472, Taf. 29–38.

Perrier, E.
'81. Études sur l'organisation des Lombriciens terrestres. Arch. Zool. exp., Tome 9, No. 2, pp. 175–248, Pls. 13–23.

Pruvot, G.
'85. Recherches anatomiques et morphologiques sur le système nerveux des Annélides polychètes. Arch. Zool. exp., série 2, Tome 3, pp. 211–336, Pls. 11–16.

Rath, O. vom.
'93. Beiträge zur Kenntnis der Spermatogenese von Salamandra maculosa. Theile I. u. II. Zeit. f. wiss. Zool., Bd. 57, Heft 1, pp. 97–185, Taf. 7–9.

Rath, O. vom.
'95. Zur Conservirungstechnik. Anat. Anzeiger, Bd. 11, No. 9, pp. 280–288.

Retzius, G.
'92. Das sensible Nervensystem der Polychäten. Biolog. Untersuch., N. F., Bd. 4, pp. 1–10, Taf. 1–3.

Retzius, G.
'92ª. Ueber die neuen Prinzipien in der Lehre von der Einrichtung des sensiblen Nervensystems. Biolog. Untersuch., N. F., Bd. 4, pp. 49–56, 9 Figg.

Retzius, G.
'95. Zur Kenntniss des Gehirnganglions und des sensiblen Nervensystems der Polychäten. Biol. Unters., N. F., Bd. 7, pp. 6–11, Taf. 2, 3.

Rohde, E.
'87. Histologische Untersuchungen über das Nervensystem der Polychaeten. Zool. Beiträge (Schneider), Bd. 2, Heft 1, pp. 1–81, Taf. 1–7.

Schaffer, J.
'96. Ueber einen neuen Befund von Centrosomen in Ganglien- und Knorpelzellen. Sitzb. Akad. Wissensch. Wien, math.-naturw. Cl., Bd. 105, Heft 2, Abth. 3, pp. 21–28, 1 Taf.

Schultze, H.
'78. Die fibrilläre Structur der Nervenelemente bei Wirbellosen. Arch. f. mikr. Anat., Bd. 16, Heft 1, pp. 57–111, Taf. 5, 6.

Semper, C.
'74. Die Stammesverwandtschaft der Wirbelthiere und Wirbellosen. Arbeit. zool.-zoot. Inst. Würzburg, Bd. 2, pp. 25–76. Taf. 3–5.

Semper, C.
'76. Die Verwandtschaftsbeziehungen der gegliederten Thiere. III. Strobilation und Segmentation. Arbeit. zool.-zoot. Inst. Würzburg, Bd. 3, pp. 115–404, Taf. 5–15.

Spengel, J. W.
'80. Beiträge zur Kenntnis der Gephyreen. II. Die Organization von Echiurus Pallasii. Zeit. f. wiss. Zool., Bd. 34, Heft 3, pp. 460–538, Taf. 23–26.

Spengel, J. W.
'81. Oligonathus Bonelliæ, eine schmarotzende Eunice. Mitth. Zool. Stat. Neapel, Bd. 3, Hefte 1 u. 2, pp. 15–52, Taf. 2–4.

Vejdovský, F.
'78. Beiträge zur Kenntniss der Tomopteriden. Zeit. f. wiss. Zool., Bd. 31, Heft 1, pp. 81–100, Taf. 6, 7.

Vedjovský, F.
'79. Beiträge zur vergleichenden Morphologie der Anneliden. I. Monographie der Enchytraeiden. Prag, 62 pp., 14 Taf.

Vedjovský, F.
'82. Untersuchungen über die Anatomie, Physiologie und Entwicklung von Sternaspis. Denkschr. Akad. Wissensch. Wien, math.-naturw. Cl., Bd. 43, Abth. 2, pp. 33–80, Taf. 1–10.

Vedjovský, F.
'84. System und Morphologie der Oligochaeten. Prag, 172 pp., 16 Taf.

Vignal, W.
'83. Recherches histologiques sur les centres nerveux de quelques invertébrés. Arch. Zool. exp., série 2, Tome 1, No. 2, pp. 267–412, Pls. 15–18.

Vom Rath, O. *See* **Rath, O. vom.**

Waldeyer, W.
'91. Ueber einige neuere Forschungen im Gebiete der Anatomie des Centralnervensystems. Deutsch. med. Wochenschrift, Jahrg. 1891, No. 44.
Also separate. G. Thieme, Leipzig, 1891, 64 pp., 10 Figg.

EXPLANATION OF PLATES.

All the figures in Plates **1–5**, and **8**, except Figures 19, 20, and 68, represent preparations from *Clymene producta*. Figures 19, 20, and 68, and all the Figures of Plates **6** and **7** represent preparations from *Axiothea torquata*.

The magnification of all the giant cells is 1000 diameters, and the method of preparation, unless otherwise stated, was by the vom Rath mixture, defined at page 232.

All figures were drawn with the aid of the Abbé camera lucida.

ABBREVIATIONS.

A.	Anterior.	*med.*	Medullary sheath.
can. gl.	Pore canal of gland.	*mu. crc.*	Circular muscles.
cd. n.	Nerve cord.	*mu. lg.*	Longitudinal muscles.
cl. cols.	Giant cell.	*o. sns.*	Sense organ.
cl. gl.	Gland cell.	*P.*	Posterior.
cl. h'drm.	Hypodermis cell.	*pli. pr'b.*	Folds of proboscis.
cl. n.	Nerve cell.	*po. gl.*	Gland pore.
cl. sns.	Sense cell.	*set.*	Seta.
c'sph.	Centrosphere.	*set. sns.*	Sense hair.
cta.	Cuticula.	*v.*	Ventral.
d.	Dorsal.	*vac.*	Vacuole.
fbr. cols.	Leydig's fibre.		

PLATE 1.

Figs. 1–3. Sections from three giant ganglion cells.

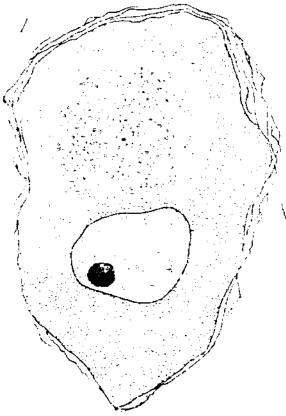
Fig. 1. Section showing relation of nucleus and sphere.

Fig. 2. Section showing centrosome and centrosphere with radiations.

Fig. 3. Section showing in addition flattening of nuclear membrane on the side toward the sphere.

Fig. 4. Tangential section of body wall to show branching and anastomosing of nerves beneath the hypodermis. × 300.

Fig. 5. Cross section of nerve cord in the region of the sub-œsophageal ganglion, showing the symmetrically placed giant cells and cross sections of the two forks of Leydig's fibre. (Drawn by K. Hyashi.)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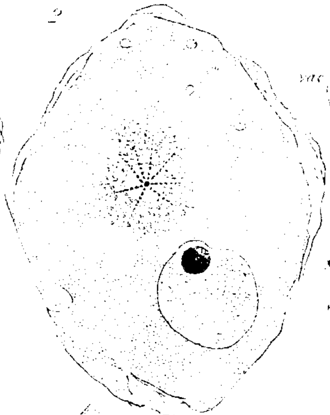
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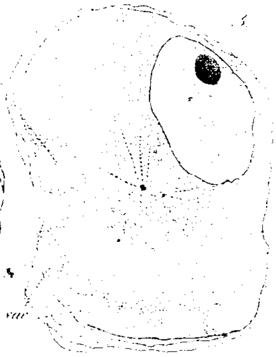
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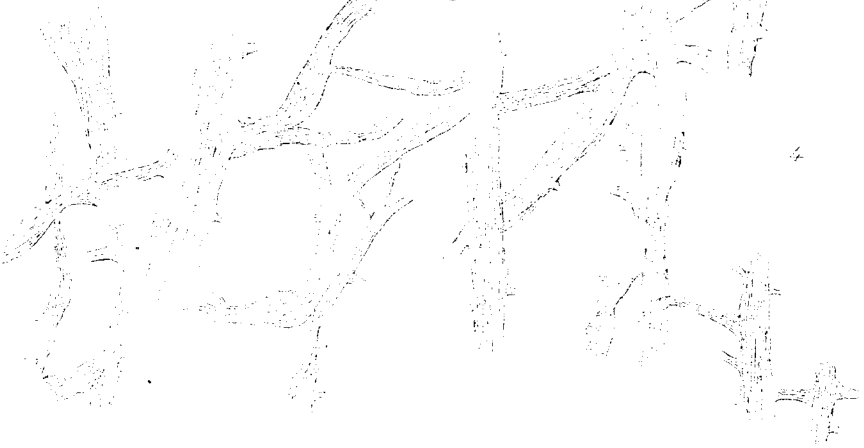
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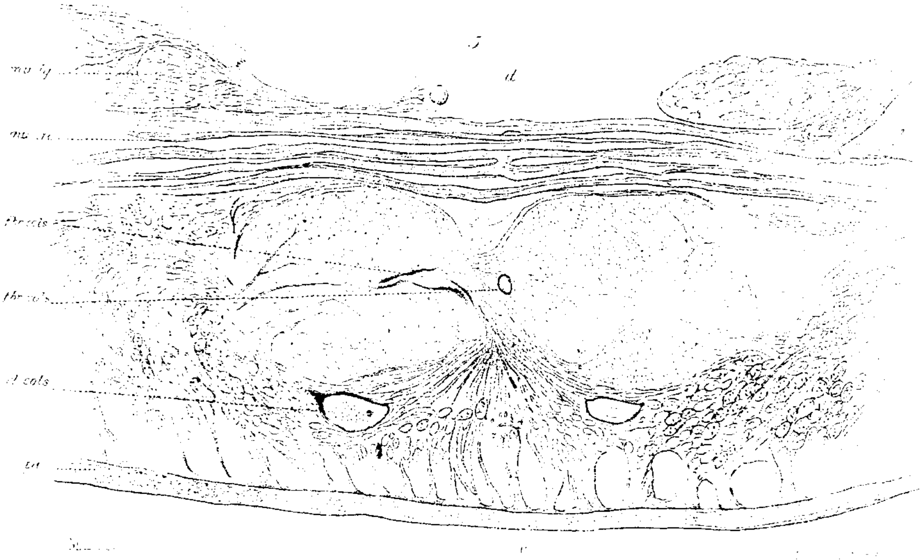
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PLATE 2.

Figs. 6, 7. Diagrams of the nerve cord in the ninth and tenth segments respectively, to show the distribution of the giant ganglion cells and their relation to Leydig's fibre. The two horizontal lines mark the position of the setæ. The two figures are to be imagined as united at β.

Figs. 8, 9. Sections of different giant ganglion cells from the region of the subœsophageal ganglion, showing in each cell two spheres, each with centrosome and radiations. The nucleus was not cut in either case.

Fig. 10. Section of giant ganglion cell, showing an outpocketing of the cell in which the nucleus lies.

Figs. 11, 12. Sections of different ganglion cells, showing centrosome and radiations.

Figs. 13, 14. Two successive sections of the same cell, showing nucleus and two centrospheres.

N. B. By an error in transferring, Figure 14 is upside down.

Fig. 15. Cross section of Leydig's fibre. × 1000.

Fig. 16. Longitudinal section of Leydig's fibre. × 1000.

Lewis-[illegible] Syst. [illegible]. Plate 2.

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PLATE 3.

Figs. 17, 18. Sections of hypodermis, each passing through a single sense organ, and showing sensory hairs. Vom Rath preparations. × 640.

Fig. 19. Piece of removed cuticula, highly magnified, and showing the area over a sense organ. The minute circles within the circular area mark the positions of pore canals accommodating the sensory hairs. The small circles outside the area represent gland pores. × 1000.

Fig. 20. Piece of removed cuticula from the first segment, showing the mosaic patches upon which the sense organs are found. These are indicated by concentric circles, some of the gland pores by a small circle and cross. × 120.

Fig. 21. Cross section of nerve cord and body wall, to show topographical relations. Vom Rath preparation. × 640.

LEWIS: NERV. SYST. POLYCHAETA.

PLATE 3.

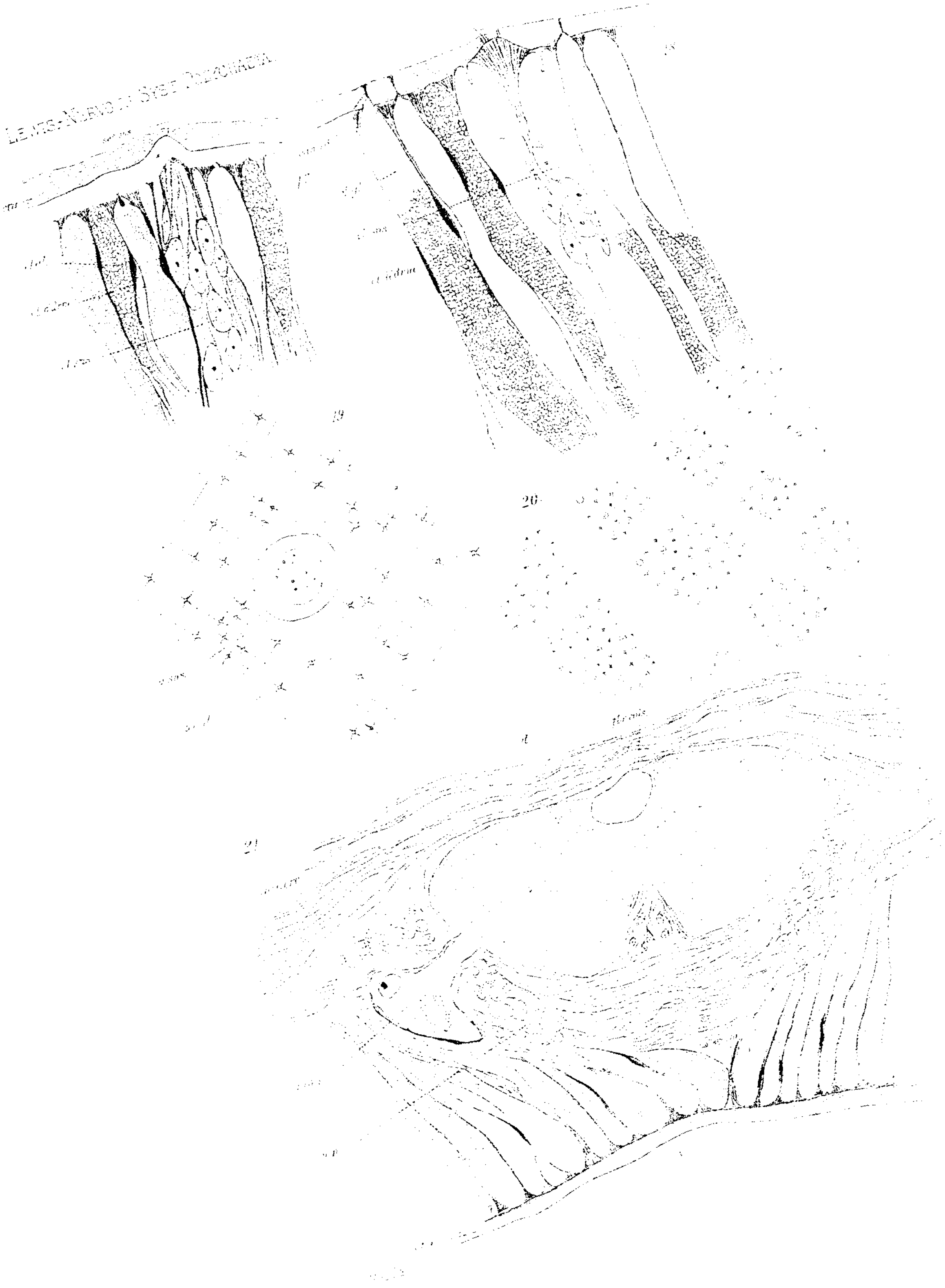
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PLATE 4.

Figs. 22, 23. Successive longitudinal sections of nerve cord, showing relation of giant ganglion cell to Leydig's fibre. Vom Rath preparation. × 750.

Fig. 24. Section of giant cell, showing centrosome composed of several corpuscles.

Fig. 25. Section of giant cell, showing eccentric position of the nucleus and the band of denser protoplasm surrounding the sphere.

Fig. 26. Section of giant cell, showing centrosome with radiations and pole of the cell. The protoplasm is slightly shrunken away from the sheath of the cell on one side. Iron hæmatoxylin preparation.

LEWIS-NERVOUS SYST PULMONATA. PLATE 4.

PLATE 5.

Figs. 27–30. Four successive sections through one cell.
Fig. 27. Section through nucleus, showing two nucleoli.
Fig. 28. Section through nucleus and outer zone of sphere.
Fig. 29. Section through sphere and centrosome. Both Figures 28 and 29 show the band of denser protoplasm partially surrounding the sphere.
Fig. 30. Section through sphere and centrosome, showing a central corpuscle, probably not the one shown in Figure 29.
Fig. 31. Section of giant cell, showing the outpocketing of the cell in which the nucleus is contained.
Fig. 31ᵃ. Section of cell from the region of the sub-œsophageal ganglion, showing nucleus and two spheres.
Fig. 32. Section immediately following the one shown in Figure 31. Radiations extend far out through the protoplasm of the cell.
Figs. 33, 33ᵃ, 34. Sections through different giant cells, to show relation of the sphere and nucleus to the cell process.

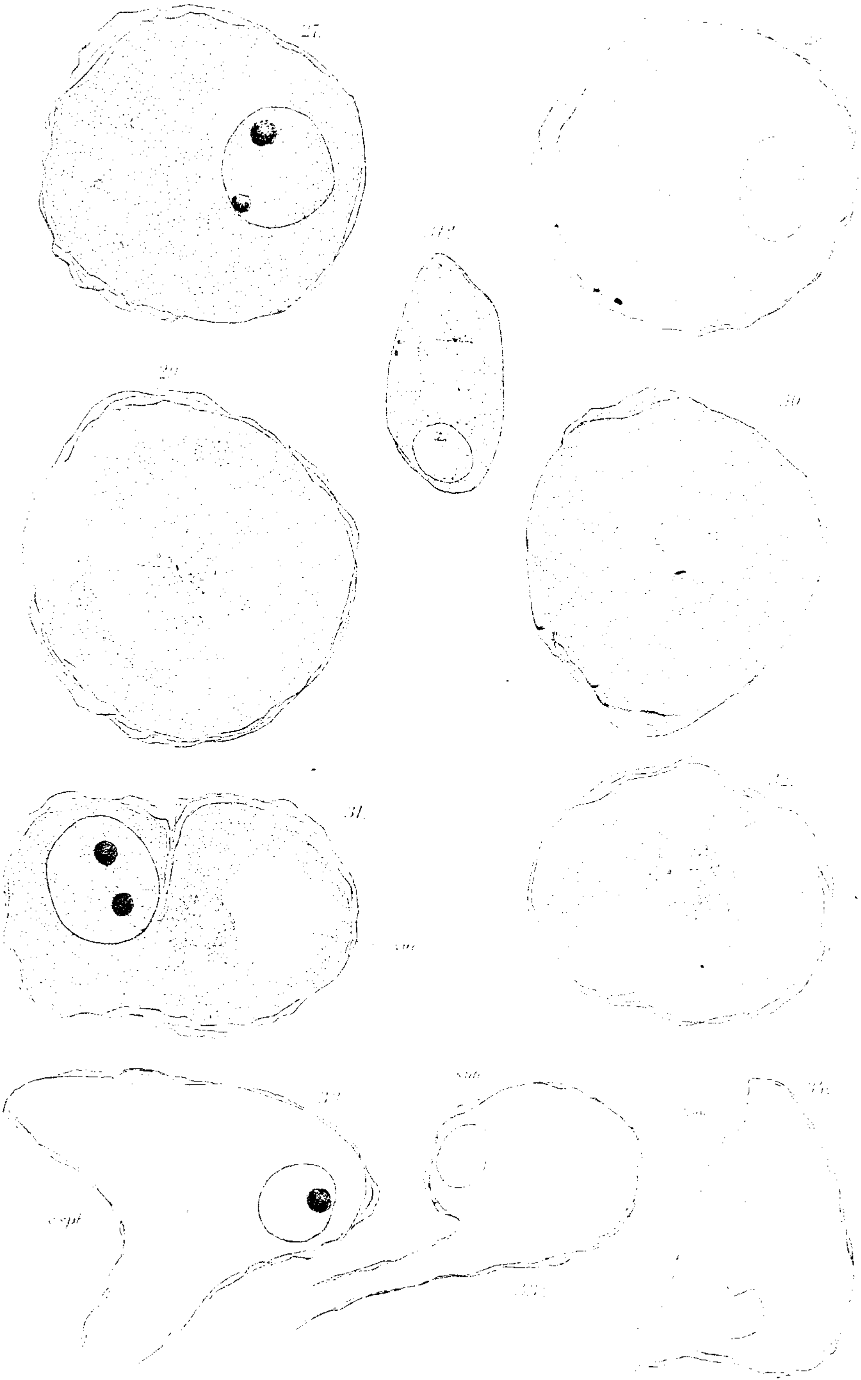
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PLATE 6.

All the figures shown in Plate 6 represent sections through sense organs from *Axiothea torquata* stained with methylen blue. All are drawn to a magnification of 750 diameters, with the exception of Figures 37 and 46, which were drawn under a $\frac{1}{18}$ (Zeiss) homogenous immersion lens.

Fig. 37. Section showing the peripheral portion of the cells drawn in Figure 38, more highly magnified.

Fig. 44. Section through a sense organ on the ventral side of the worm, showing one cell belonging to the sense organ, and four belonging to the central nervous system (compare Plate 3, Fig. 21, *cl. n.*). In two cells the nucleus was clearly distinguishable; in two it was not. The single continuous line farthest from the cuticula indicates the boundary of the fibrous portion of the ventral nerve cord.

Fig. 47. The line farthest from the cuticula indicates the boundary of circular muscles.

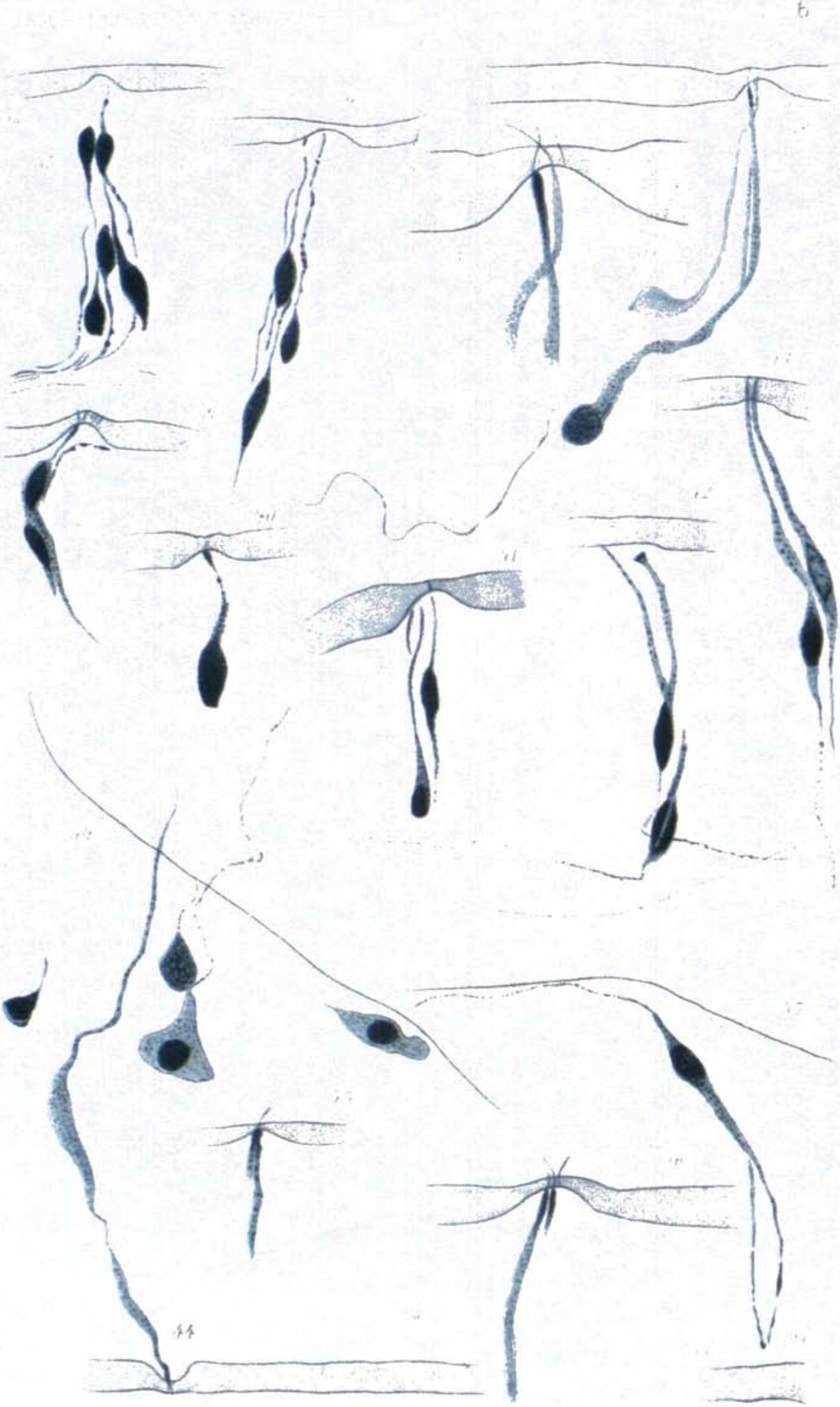
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PLATE 7.

Figs. 48–52. Sections through sense organs of *A. torquata*, showing sensory cells stained with methylen blue. × 750.

Figs. 53–62. Cells from the central nervous system of *A. torquata*, stained with methylen blue. × 750.

Figs. 63–65. Ordinary hypodermis cells from *A. torquata*, stained with methylen blue. × 750.

7.

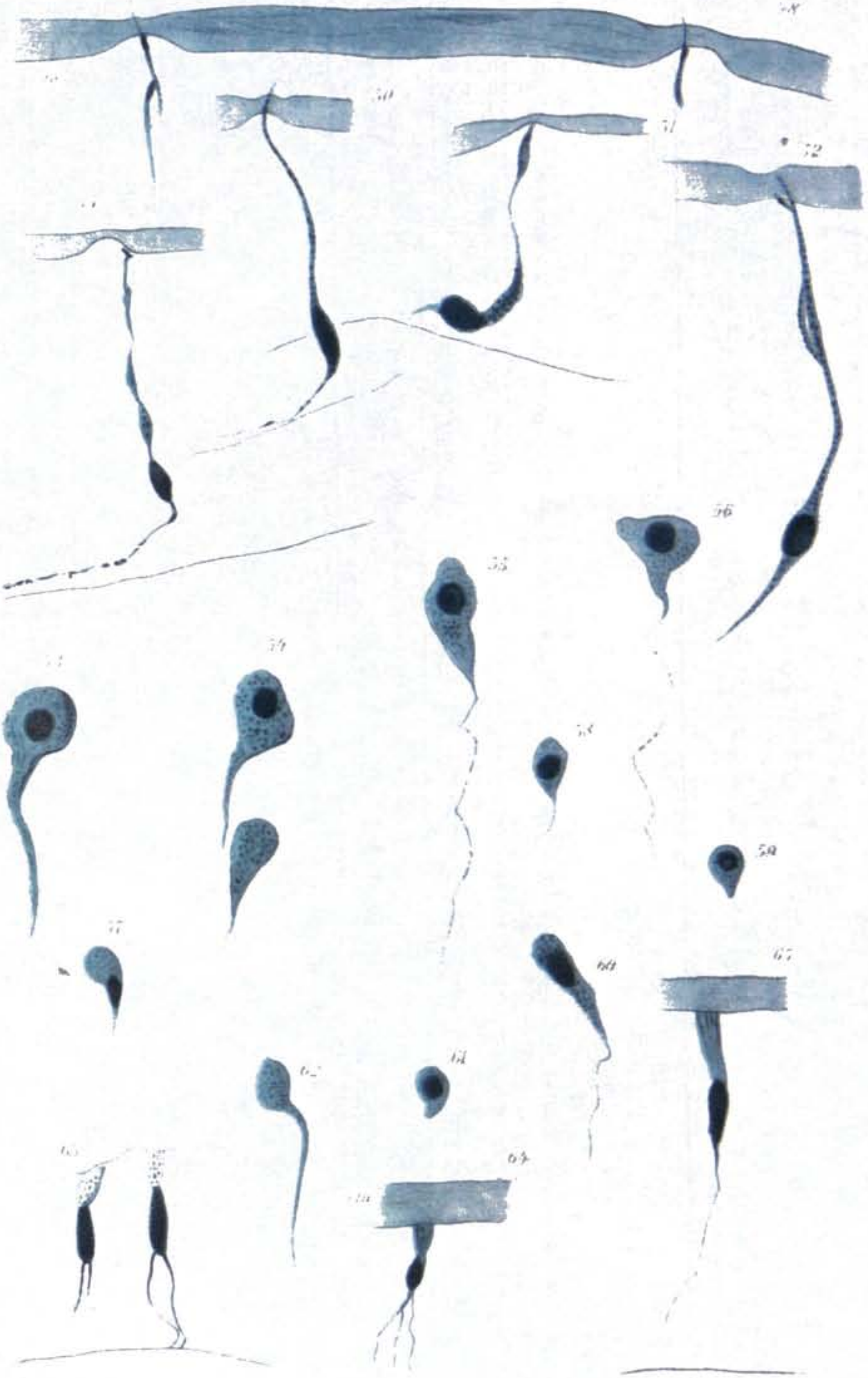
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PLATE **8.**

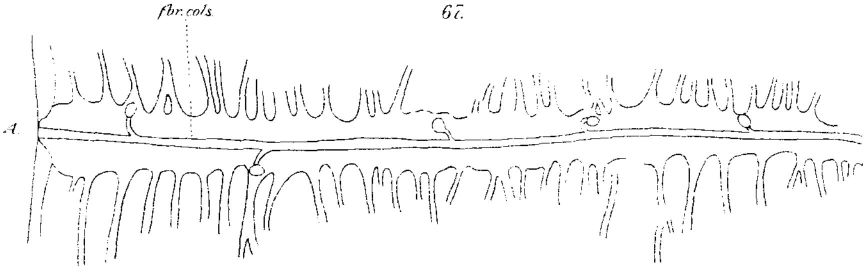
Figs. 66, 67. Diagrams of portions of nerve cord in *Clymene producta.*

Fig. 66. Nerve cord in the anterior part (about $\frac{2}{3}$) of segment 5, showing the lateral nerves, giant cells, and Leydig's fibre. × 40.

Fig. 67. Nerve cord in the anterior part (about $\frac{3}{4}$) of segment 3. × 40.

Fig 68. Diagram showing distribution of sense organs of right half of the first four segments of *Axiothea torquata.*

67.



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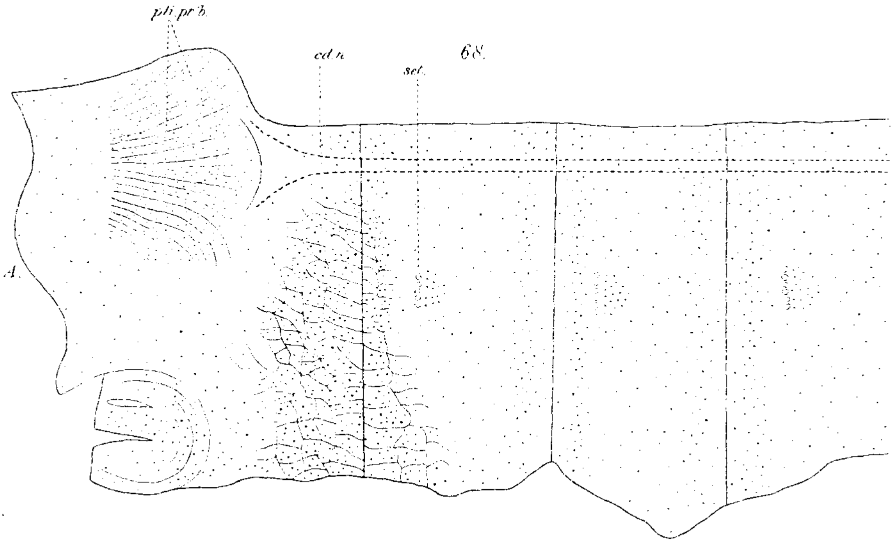
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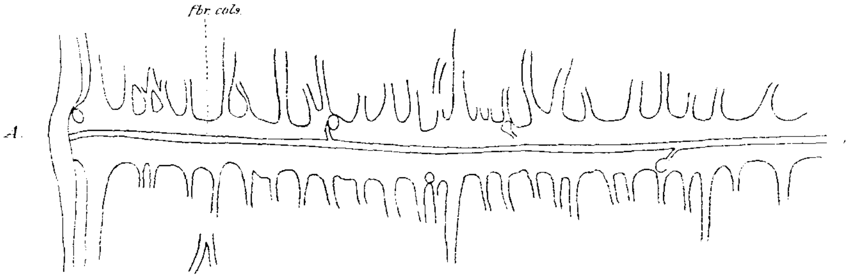

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Proceedings of the American Academy of Arts and Sciences.

Vol. XXXIII. No. 15. — April, 1898.

THE ORTHOPTERAN GROUP SCUDDERIÆ.

By Samuel H. Scudder.

With a Plate.

THE ORTHOPTERAN GROUP SCUDDERIÆ.

By SAMUEL H. SCUDDER.

Presented June 9, 1897.*

THE Scudderiæ are Phaneropterine Locustarians in which the fastigium of the vertex is slightly deflexed, acuminate or subacuminate, no broader than the first antennal joint, the pronotum plane above and in no way sellate, the fore coxæ armed with a spine, the fore tibiæ sulcate above with acute margins and the genicular lobes of the hind femora blunt, armed only with a feeble spine or spines.

There are but three genera in this strictly American † group, the one here added easily distinguished from the others by the unusual breadth of the front of the fastigium of the vertex, and represented by a single species found in California. One of the other genera also has but a single species in North America, but unlike the others is represented elsewhere. Only the North American forms are considered in this paper. The third genus, from which the group takes its name, is more abundant in species, two of which are described here for the first time, while the somewhat tangled synonymy indicates in what confusion the names have been employed. These three genera may be distinguished by the following table: —

Table of the genera of Scudderiæ.

a^1. Fastigium of vertex between the antennæ less than half the width of the basal antennal joint; mesosternum not more than half as broad again as long; tegmina and wings of unequal length, both surpassing the hind femora; tegmina four or more than four times as long as broad, the tympanum of male twice as long as broad, with nearly straight sides and crossed by a single stout vein; genicular lobes of hind femora armed at apex with a single distinct but not very long spine.

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* Subsequently rewritten.

† One species is credited to Africa, but it may be doubted whether it strictly belongs here.

b^1. Fore and middle femora unarmed beneath, the hind femora either unarmed or with few and inconspicuous spines beneath; subgenital plate of male long, slender, apically V-shaped in cross section and with few exceptions apically compressed . . . . *Scudderia.*

b^2. All the femora distinctly spinulose beneath; subgenital plate of male short and broad, apically with a broad rounded emargination. *Symmetropleura.*

a^2. Fastigium of vertex between the antennæ nearly as broad as the basal antennal joint; mesosternum about twice as broad as long; tegmina and wings of equal length, not surpassing the hind femora; tegmina hardly more than three times as long as broad, the tympanum of male but little longer than broad with very arcuate sides and crossed by a pair of stout veins; genicular lobes of hind femora armed apically with a pair of minute spines . . . . *Platylyra.*

SCUDDERIA Stål.

Scudderia Stål, Öfv. k. Vet.-Akad. Förh., XXX., 41 (1873); Rec. Orth., II., 14 (1874).

This genus, which combines a very narrow fastigium between the eyes with fore and middle femora unarmed beneath, has for its most striking feature the peculiar armature of the male abdomen, which, however, is greatly modified in two of the species; it consists in the highly developed structure of the anal segment, which is greatly produced, bearing a pistillate, more or less decurved process, and this bears beneath at base a compressed, depending, securiform lamina, and at tip is forked or notched to receive and partially embrace the apical portion of the long, tapering, upcurved, subgenital plate.

The genus is confined to North America, where it is widely distributed from the central portions of Central America to Canada, but appears to be quite absent from the Antilles. In Brunner's first monograph of the Phaneropterinæ, certain South American forms were placed with the North American, but in his supplement to that work he has separated them. One species, however, occurs in Panama. The number of species is not great, less than a dozen being known, but they have been frequently confused and are sometimes difficult to separate, especially the females.

As regards the structure of the anal segment of the male, the species of Scudderia show four main types, according to which they may be grouped. In one, the expanded apical portion is shaped somewhat (in one species remarkably) like an ox-hoof, the lobes tumid and apically rounded, and the cleft between them distinct, deep, and parallel, or almost parallel; in another the lobes become laterally expanded flattened flanges, separated by a moderately deep rectangular or subrectangular emargination; in the third, the lateral flanges are vertical, being compressed instead of depressed, and are widely separated by a moderately deep but abrupt and wide apical emargination, the base of which is broadly transverse and has a minute median projection; in this group the process completely embraces laterally the upturned subgenital plate, although the latter is exceptionally broad, and not, as in the other types, more or less strongly compressed apically; finally, in a fourth group, the segment is not produced at all, and the species which fall under it are very diverse in the structure of the subgenital plate, which is otherwise very similar throughout the genus.

These distinctions have been used as the basis of the separation of the males of this genus in the following table: —

Table of the species of Scudderia, based upon the male.

a^1. Anal segment expanded apically into a pistillate process; subgenital plate strongly compressed apically, though more or less depressed basally; cerci relatively short and more or less strongly incurved.

 b^1. Anal segment apically truncate with a minute median projection and compressed, completely vertical, lateral flanges, which project beyond the main body posteriorly, and so completely embrace and generally extend beyond the sides of the subgenital plate when in natural position . . . . 1. *texensis.*

 b^2. Produced claviform or pistillate apical portion of anal segment, as seen from above, generally considerably expanded and always deeply and narrowly or distinctly and angularly emarginate at apex, with no median projection, the lateral lobes touching only and not fully embracing the sides of the subgenital plate when in place, and never surpassing it.

  c^1. Anal segment subrectangularly emarginate at apex, the lateral lobes depressed, laterally expanded, laminate.

   d^1. Tegmina much broader than depth of body and relatively short, at most not much over four times longer than middle breadth, the principal vein distinctly flexuous; apical flanges of anal segment subtriangular, distinctly tapering . 2. *pistillata.*

   d^2. Tegmina no broader than depth of body and relatively long, nearly or more than five times longer than middle breadth, the principal vein nearly straight; apical flanges of anal segment well rounded, subequal in breadth.

e^1. Tegmina relatively broad, in the middle (and especially in the female) distinctly broader than the length of the pronotum; lateral lobes of pronotum nearly vertical, subacutely separated from the disk by lateral canthi; depending, compressed, securiform basal plate of anal segment of medium size . . . . 3. *curvicauda.*

e^2. Tegmina relatively narrow, in the middle distinctly narrower than the length of the pronotum; lateral lobes of pronotum flaring below, very obtusely separated from the disk, there being no sign of lateral canthi; depending, compressed, securiform basal plate of anal segment of exceptional size. 4. *laticauda.*

c^2. Anal segment very deeply and narrowly emarginate at apex, the sides of the emargination or fissure parallel or nearly so, the lateral lobes variously developed but generally incrassate, separated by a space too narrow properly to admit the subgenital plate.

d^1. Each lateral half of the expanded apical portion of anal segment about twice or more than twice as long as broad, subcylindrical, the deep apical emargination narrow with parallel sides.

e^1. The apical expanded portion of anal segment conspicuously emarginate in the middle, as seen laterally, the apical lateral flanges more or less obliquely compressed and laminate; hind femora with a few spines beneath on inner margin only. 5. *mexicana.*

e^2. The apical lateral lobes of the anal segment forming subcylindrical, subcompressed, and rounded masses, not laterally emarginate; hind femora spined beneath on both margins.

f^1. Lateral canthi of pronotum subdistinct, at least posteriorly; subgenital plate conspicuously surpassing the tip of the anal segment, the latter with no lamina depending between the cerci at its base . . . . 6. *ungulata.*

f^2. Lateral canthi of pronotum entirely wanting; anal segment just reaching the apex of the subgenital plate, and with a conspicuous, backward-directed median lamina depending from its base between the cerci, forming a calcariform process . . . . 7. *paronæ.*

d^2. Apical portion of anal segment forming a cleft unguliform body, very deeply emarginate apically, each lateral half consisting of a swollen mass not greatly longer than broad, the apical emargination somewhat less deep than in the alternate category, but generally with parallel or subparallel sides.

e^1. Enlarged apical portion of anal segment broadest, when viewed from above, at the middle of the apical emargination, unicolorous, less pronounced, the arms of the fork less tapering, as much compressed as depressed, with no prominent basal heel, and hardly triangular as seen laterally . . . 8. *furcifera.*

e^2. Enlarged apical portion of anal segment broadest, when viewed from above, at the base of the apical emargination, more or less infuscated, more pronounced, the arms of the fork more tapering, more depressed than compressed, often conspicuously swollen at base and with a prominent basal heel, and more or less triangular as seen laterally . . 9. *furcata.*

a^2. Anal segment triangular or transversely quadrate with no apical process; subgenital plate depressed throughout; cerci relatively long and gently arcuate.

b^1. Anal segment triangular, apically angulate; subgenital plate apically incised to a depth less than the middle breadth of the plate, the lobes divaricate; cerci tapering, apically acuminate; hind femora spined beneath on inner margin only or not at all.
10. *septentrionalis.*

b^2. Anal segment transversely quadrate, apically truncate; subgenital plate apically incised to half its length, forcipiform, the lobes oppositely arcuate; cerci hardly tapering, apically bifid or biangulate; hind femora spined beneath on both margins . . . . . . 11. *forcipata.*

The females of the species of Scudderia are relatively difficult to separate, as Saussure has already remarked. The following table for their determination has therefore been constructed with much difficulty, and will sometimes fail to prove entirely satisfactory.

Table of the species of Scudderia, based upon the female.

(The females of *S. paronæ* Griff., and *S. forcipata* Brunn., are not known.)

a^1. Ovipositor bent as well as curved, generally (excl. *laticauda*) distinctly less than half as long again as pronotum.

b^1. Disk of pronotum distinctly broadening from in front backward; few or no spinules on the inner carina of underside of hind femora.

c^1. Disk of pronotum distinctly less than half as long again as its posterior breadth, distinctly dilating posteriorly; tegmina less than four times as long as broad . . . . 2. *pistillata.*

c^2. Disk of pronotum half as long again as its posterior breadth, less dilated posteriorly; tegmina nearly or quite five times as long as broad.

d^1. More compressed forms, with relatively longer legs, slenderer pronotum with deeper lateral lobes, and with the serrations of the margins of the ovipositor more prominent . . 1. *texensis.*

d^2. More robust forms, with relatively shorter legs, stouter pronotum, with shallower lateral lobes, and with the serration of the margins of the ovipositor less prominent . 3. *curvicauda.*

b^2. Disk of pronotum with parallel or nearly parallel sides.

c^1. Pronotum with very rounded shoulders between lateral lobes and disk; 5–6 spinules on inner carina of under surface of hind femora . . . . 4. *laticauda.*

c^2. Pronotum sharply shouldered where the lateral lobes join the disk; few or no spinules on the inner carina of under surface of hind femora.

d^1. Larger and more elongate forms, with slenderer pronotum; tegmina about five and a half times as long as broad; wings in repose extending beyond tegmina by distinctly more than the length of the pronotum; hind femora nearly as long as tegmina. 5. *mexicana.*

d^2. Smaller and less elongate forms with stouter pronotum; tegmina about five times as long as broad; wings in repose extending beyond tegmina by not more than the length of the pronotum; hind femora very much shorter than tegmina.

e^1. Basal plica of ovipositor not marked with black. 8. *furcifera.*

e^2. Basal plica of ovipositor generally marked with black. 9. *furcata.*

a^2. Ovipositor curved but hardly bent, more than half as long again as pronotum.

b^1. Tegmina much more than 30 mm. long, about five times as long as broad and nearly six times as long as pronotum; hind femora with several spines on each margin beneath; ovipositor narrower in middle than toward base, tapering through at least the apical third; lateral lobes of pronotum as deep as broad . . . . . 6. *ungulata.*

b^2. Tegmina much less than 30 mm. long, less than four times as long as broad and five times as long as pronotum; lateral lobes of pronotum distinctly broader than deep; hind femora with a single spine or two on each margin beneath . . . . 10. *septentrionalis.*

1. Scudderia texensis. Fig. 1.

Scudderia texensis Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 330, pl. 15, figs. 18, 19 (1897).

Scudderia curvicauda Blatchl. ! [nec De Geer], Proc. Ind. Acad. Sc., 1892, 99–100 (1894).

" " Beut. !, Bull. Amer. Mus. Nat. Hist., VI., 275, pl. 7, figs. 5, 6 (1894).

Some specimens from S. Carolina, Georgia, and Florida have a distinctly more compressed form, without luteous canthi, and with slenderer and longer lateral flanges on the pistillate portion of the anal segment of the male; but I have found so much variation and gradation in all these points that it seems hardly proper to regard them as even a variety.

Norway, Oxford Co., Me., Smith (M. C. Z.). Mass. (S. H. S.); Newtonville and Sherborn (Morse), and Malden (Sprague), Middlesex Co.; Vicinity of Boston (Morse); Canton, Walpole, and Wollaston (Sprague), Norfolk Co.; and West Chop, Dukes Co. (Morse), Mass. Thompson, Windham Co., Montville, New London Co., North Haven, New Haven Co., South Kent and Canaan, Litchfield Co., and Stamford, Fairfield Co. (Morse), Conn. New York (S. H. S.); Long Island, N. Y. (S. H. S.). Maryland, Uhler (S. H. S.). Michigan, Miles (S. H. S.). Chillicothe, Ross Co., Denton (Morse), Ohio. Vigo and Putnam Co., Blatchley (S. H. S.), Ind. Illinois, Uhler (S. H. S.), Stromberg (M. C. Z.); Chicago (S. H. S.); and Watertown, Rock Isl. Co., McNeill (S. H. S.), Ill. Jefferson, Green Co., Allen (S. H. S.), and Dallas Co., Allen (S. H. S.), Iowa. West Point, Cuming Co., and Lincoln, Lancaster Co. (Bruner), Nebr. Ogden, Utah, Edwards (Beutenmüller). Georgia, Oemler and Morrison (S. H. S.). South Carolina (S. H. S.). Florida, Uhler (S. H. S.), and Morrison (M. C. Z.); Sandford, Orange Co., Frazer (S. H. S.), and Jacksonville, Duval Co., Ashmead and Priddey (Bruner), Florida. Texas, and Dallas, Texas, Belfrage, Boll, Agassiz (M. C. Z., S. H. S.).

2. Scudderia pistillata. Fig. 2.

Scudderia pistillata Brunn., Mon. Phaneropt., 240–241 (1878).

" " Beut., Bull. Amer. Mus. Nat. Hist., VI., 276–277 (1894).

" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 332 (1897).

Scudderia curvicauda Scudd.! (pars) [nec De Geer] Bost. Journ. Nat. Hist., VII., 448 (1862).

Scudderia furculata Blatchl.! [nec Brunn.], Proc. Ind. Acad. Sc., 1892, 100–101 (1894).

Halifax, Nova Scotia, Piers (S. H. S.). Winnipeg, Manitoba, Kennicott (S. H. S.), Scudder (M. C. Z.). Moosehead Lake (S. H. S.); Mt. Desert Is. (S. H. S.); and Norway, Smith (M. C. Z., Morse), and Bethel, Edmands (M. C. Z.), Oxford Co., Me. New Hampshire (t. Brunner); White Mts., valleys and subalpine (S. H. S.); and Franconia, Slosson (S. H. S.) and Bethlehem, Agassiz (M. C. Z.), Grafton Co., N. H. Mass. (S. H. S.); Adams, Berkshire Co. (Morse); Newton, Middlesex Co., Henshaw (M. C. Z.); Wollaston and Walpole, Norfolk Co. (Sprague); and Provincetown, Barnstable Co. (Morse), Mass. Chateaugay Lake, Adirondacks, Bowditch (S. H. S.) and Ithaca, Tompkins Co. (Morse), N. Y. New Jersey (t. Smith). Michigan, Miles (S. H. S.). Marshall, Fulton, Vigo and Putnam Co., Ind. (Blatchley). Southern Illinois, Thomas (S. H. S.). Iowa (t. Osborn, Ball). Nebraska, Dodge (S. H. S.), and West Point, Cuming Co. Bruner, (S. H. S.), Nebr. Bismarck, Burleigh Co., N. Dak. (Bruner). Georgia (t. Saussure-Pictet).

This is a northern species, and the last reference above is surprising, the most southerly stations otherwise known being Southern Illinois and Central Indiana.

3. Scudderia curvicauda. Fig. 3.

Locusta curvicauda De Geer!, Mém., III., 446, pl. 38, fig. 3 (1773).

Gryllus (Tettigonia) curvicaudus Goeze, Ent. Beytr., II., 98 (1778).

Phaneroptera angustifolia Harr.!, Ins. Inj. Veg., 129 (1841).

Phaneroptera curvicauda Scudd.! (pars[*]), Bost. Journ. Nat. Hist., VII., 448 (1862).

Scudderia curvicauda Stål, Öfv. k. Vet.-Akad. Förh., XXX., 41 (1873).

" " Brunn., Mon. Phaneropt., 240 (1878).

" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 331–332, pl. 15, fig. 20 (1897).

Scudderia furculata Beut.! [nec Brunn.], Bull. Amer. Mus. Nat. Hist., VI., 275 (1894).

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[*] Specimens in my collection and in that of the Museum of Comparative Zoology used by me in 1862, as well as my own words at the time, show that I did not then distinguish between this species and *S. pistillata*; and, as specimens then sent to Brunner further show, neither did I distinguish *S. septentrionalis*. I have accordingly quoted this reference under each of these species.

I follow Stål and Brunner in the determination of this as De Geer's species, aided by a specimen still in my possession, which I compared with the type more than thirty years ago and identified as the same.

After an examination of Harris' types of his *Phan. angustifolia* in 1862, I agreed with Uhler (Harr., Ins. Inj. Veg., 3 ed. 161, note) that it was the same as *curvicauda* De Geer; but at that time, as stated in my note above, I recognized but a single species in New England, so that in the present study of the species I have not been very confident of my former determination. At present there remains only a damaged tegmen of one specimen and the pronotum of another, but by their aid and by careful and repeated comparisons of New England specimens of all the species occurring there I still find that *angustifolia* must be regarded as a synonym of *curvicauda*. The tegmen is much too large for New England specimens of either *furcata* or *septentrionalis*, too slender for *pistillata*, and agrees better, as does the broader pronotum, with *curvicauda* than with *texensis*, which last, moreover, is a much rarer species in New England. Brunner was led into regarding *septentrionalis* as Harris' *angustifolia* from my sending him specimens of *septentrionalis* marked as *curvicauda*, and by the absence in Harris' description of any reference to a pistillate anal segment, while mentioning the subgenital plate; but the specimens preserved, such as they are, entirely preclude this, and Harris' running description was so general and so little technical that the absence of mention of the peculiar anal segment is not surprising.

Fryeburg, Oxford Co., Me. (Morse). Hampton (S. H. S.), and Kingston, Denton (Morse), Rockingham Co., N. H. Brandon, Rutland Co., (S. H. S.), and Brattleboro', Windham Co. (Morse), Vt. South Hadley, Hampshire Co. (Morse); Gloucester, Essex Co. (Sprague); Malden (Sprague), Sherborn (Morse), and Woburn, Shute (M. C. Z.), Middlesex Co.; Wellesley, Blue Hills, and Dover (Morse), Canton, Walpole, Milton, and Wollaston (Sprague), Norfolk Co.; Scituate, Plymouth Co. (Sprague); Provincetown (Morse, S. H. S.); Hyannis (S. H. S.), and Woods Holl (Morse), Barnstable Co.; and West Chop, Dukes Co. (Morse), Mass. Wickford, Washington Co., and Block Island, Newport Co., R. I. (Morse). Thompson, Windham Co., Canaan, Litchfield Co., New Haven and North Haven, New Haven Co., and Stamford, Fairfield Co., Conn. (Morse). Long Island (S. H. S.) and Ithaca. Tompkins Co. (t. Beutenmüller), N. Y. Pennsylvania (t. De Geer). Maryland, Uhler (S. H. S.). Chillicothe, Ross Co., Ohio, Denton (Morse). Putnam, Vigo and Lake Co., Ind., Blatchley (S. H. S., Morse). Michigan, Miles (S. H. S.). Jefferson, Greene Co., and Dallas Co., Allen (S. H. S.), Iowa. Kentucky, Sanborn (M. C. Z.). North Carolina, Morrison (M. C. Z., S. H. S.). Georgia, Morrison (M. C. Z., S. H. S.). Jacksonville, Duval Co., Ashmead (Bruner), and Sandford, Orange Co., Frazer (S. H. S.), Fla. Monticello, Lawrence Co., Miss., Jamison (S. H. S.). Texas, Boll, Agassiz, Schaupp (M. C. Z.); Texas, Boll, Belfrage, "common in October in woods on plants and bushes" (S. H. S.); Gulf coast of Texas, Aaron (S. H. S.); New Braunfels, Comal Co., Lincecum (S. H. S.), Texas. Orizaba, Vera Cruz, and Tabasco, Mex. (t. Saussure and Pictet).

4. Scudderia laticauda. Fig. 4.

Scudderia laticauda Brunn., Mon. Phaneropt., 238-239 (1878).
" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 330, pl. 15, fig. 15 (1897).

This species appears in two forms; one is wholly green, the other (which may be called *strigata*) is heavily infuscated in stripes along the hind margin of the tegmina, and anterior margin of the anal area. It is found at Jacksonville, Duval Co., Fla., Priddey (Bruner). The species is credited to Georgia by Brunner, and to Georgia and Texas by Saussure and Pictet.

5. Scudderia mexicana. Fig. 5.

Phaneroptera mexicana Sauss., Rev. Mag. Zool., 1861, 129 (1861).
Scudderia furculata Brunn., Mon. Phaneropt., 239, pl. 5, fig. 72 b (1878).
" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 331, pl. 15, fig. 21 (1897).

There seems to be no reason why the name of *mexicana* should not be restored to this species.

Grant's Pass, Josephine Co., Oregon (Morse, S. H. S.). Los Angeles (Bruner) and Coronado, San Diego Co. (Morse), Cal. Texas (t. Brunner). Mexico, Botteri (S. H. S.); Matamoras, Tamaulipas, Couch (S. H. S.); Corona da California, Blaisdell (Bruner); Guerrero, Vera Cruz, and Tabasco (t. Saussure and Pictet); and Orizaba (Bruner), Mexico. Guatemala, Van Patten (S. H. S.).

6. Scudderia ungulata, sp. nov. Fig. 6.

Testaceo-flavescent,* the legs and veins of the tegmina feebly rufescent, the face luteous. Eyes rather large and prominent. Fastigium of

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* The specimens have perhaps been immersed for a short time in spirits and so lost their greenish color.

the vertex much compressed, contiguous with the frontal fastigium. Antennæ very long and slender, rufescent in the basal half, very narrowly interrupted with fuscous at the distal extremity of each joint. Pronotum with the disk scarcely enlarging posteriorly, plane or feebly convex, the front margin straight, the hind margin gently and uniformly convex, the lateral lobes vertical or subvertical, the lateral canthi fairly well marked but rounded except posteriorly, the lobes margined throughout, of equal length and breadth, very strongly convex and subangulate below, well rounded behind. Tegmina about five times as long as broad, semiopaque, glistening, the front margin basally arcuate, the apex subangulate and obliquely truncate below, the anal area exceptionally long and tapering, the principal vein a little flexuous, the radial branch forked in the middle of its course, the whole considerably surpassing the hind femora; wings longer than tegmina. Fore femora armed beneath on the front margin with 2–3 spines, the middle femora with 1–2, the hind femora with 4–5 small black spines on the inner, 3–5 on the outer margin; fore tibiæ with 2–4 spines on the outer margin above, 3–4 spines on each margin below; middle tibiæ spined above and below on each margin. Anal segment of male tumid at base, rapidly narrowing to form beyond the middle constriction a pistillate process consisting of a pair of subcylindrical rolls placed side by side, each rather shallower than broad, fully twice as long as broad, when seen laterally nowhere broader than the middle portion of the segment, straight and slightly tapering, the tip blunt; seen from above, they are together slightly broader than the middle portion of the segment, being a little tumid, cleft by a basally rounded deep emargination with subparallel sides to the middle of the pistillate portion, the whole bent downward at an obtuse angle with the base of the segment, the apical emargination not wide enough to receive any portion of the subgenital plate, the whole resembling a tuning fork with rounded arms. The subgenital plate of male considerably surpasses the anal segment, is rather strongly bent-arcuate, depressed, and tapers throughout though very little in the distal half, the extreme apex compressed and angularly excised so as to be V-shaped. Cerci of male very strongly incurved and twisted, rather stout and not very long, regularly tapering. Ovipositor half as long again as the pronotum, very regularly arcuate, tapering with considerable uniformity, bluntly pointed, the margins feebly crenulate, the whole rufo-castaneous, greenish toward base, the basal plica unmarked.

Length of body, ♂, 21 mm.; ♀, 23 mm. Pronotum, ♂, ♀, 6 mm. Tegmina, ♂, 38 mm.; ♀, 34 mm. Breadth of same, ♂, 7.75 mm.; ♀, 7? mm. Length of fore femora, ♂, 6.5 mm.: ♀, 6.25 mm. Hind femora, ♂, 28 mm.; ♀, 28.5 mm. Subgenital plate, 6 mm. Ovipositor, 9.5 mm.

1 ♂, 1 ♀, Tepic, Mexico, Prof. L. Bruner.

I do not feel entirely confident of the distinctness of this species from *S. paronæ* Griff., from Panama, which I know only by description. The greatest apparent difference is in the total absence in the single male at hand of any sign of the characteristic median compressed lamina, depending between the cerci from the base of the anal segment; but as the presence of this lamina has been determined in every other species of Scudderia I have seen which has a pistillate anal segment, I do not feel sure that it is not present and crowded forward beyond and hidden by the anal cerci, which in this specimen completely hide from view anything there may be in such a place; dissection only could determine this point. The minor points of difference from *S. paronæ* (judging by the descriptions of the latter, which are unusually full) are the somewhat larger size and considerably longer members, the presence of lateral canthi on the pronotum, the considerably greater proportionate length of the tegmina to the hind femora, which they much surpass, the flexuosity of the principal vein, the forking of the radial branch at and not before the middle, the spiniferous lower margin of the fore femora, the greater number of spines on the lower margins of the hind femora and their wholly black color, the fewer spines of the fore tibiæ and the greater length of the subgenital plate relative to the anal segment.

7. Scudderia paronæ.

Scudderia paronæ Griff., Boll. Mus. Zool. Univ. Tor., XI., No. 232, 11–13 (1896).
" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 330 (1897).

I have not seen this species, but it must be closely allied to the last. Only the male is known and is reported from Colon, Panama, by Griffini and in the Biologia.

8. Scudderia furcifera, sp. nov. Fig. 7.

Green, often more or less testaceo-flavescent, the lateral canthi of pronotum usually narrowly luteous, the face lutescent. Eyes moderately large and prominent. Fastigium of the vertex apically strongly compressed, superiorly emarginate, in close contact with the frontal fastigium. Antennæ luteo-rufescent, uniform except for a lack of rufescence next base. Pronotum with nearly parallel sides, being almost as broad posteriorly as anteriorly, the disk plane, the front margin nearly straight, the hind margin moderately convex, the lateral canthi distinct, the lateral lobes being vertical or subvertical and rectangularly inserted in the disk, slightly deeper than broad, the front margin vertical excepting below, the lower margin and hind margin each strongly convex and subangulate, the whole feebly margined. Tegmina about five times as long as broad, somewhat opaque, the anal area moderately long, the principal vein scarcely flexuous, the radial branch forked near the middle of its course, the whole only a little surpassing the hind femora; wings extending considerably beyond tegmina. Fore femora armed beneath on the front margin with 2–3 spines, the middle femora, which are much longer, unarmed, the hind femora with 1–4 spines on inner, 0–3 spines on outer margin; fore tibiæ with 1–2 spines on outer margin above, 3–4 on either margin below; middle tibiæ spined on the posterior margin only above, on both margins below. Anal segment of male rapidly and uniformly tapering to slightly beyond the middle and then expanding into a somewhat decurved thickened apical portion, consisting of two lateral oval everywhere rounded lobes, scarcely tapering, apically bluntly rounded, and separated by an equal or diverging interspace half as broad as the middle portion of the segment and formed by a deep apical emargination; the whole is pale testaceous or castaneous, nearly or quite uniform, and is broadest, when viewed from above, at the middle of the emargination. Cerci of male subcylindrical, incurved and mesially bent, not very long, moderately stout, and apically pointed. Subgenital plate of male extending but very little if at all beyond the tip of the anal segment, bent-arcuate, tapering and depressed in the basal half, subequal in the apical half, compressed and emarginate at tip, forming an arcuate V in cross section. Ovipositor somewhat longer than the pronotum, not very broad, bent-arcuate beyond the base, the tip rounded subacuminate, the margins densely crenulato-dentate, the whole castaneous, the basal plica luteous.

Length of body, ♂, 17 mm.; ♀, 21 mm. Pronotum, ♂, 5.2 mm.; ♀, 5.1 mm. Tegmina, ♂, 29.5 mm.; ♀, 28 mm. Middle breadth of same, ♂, 6.5 mm.; ♀, 6 mm. Length hind femora, ♂, 23 mm.; ♀, 24.5 mm. Ovipositor, 6.5 mm.

11 ♂, 2 ♀. Medellin, Vera Cruz, Mexico, Heyde; Tepic, Jalisco, Mex.; both received from Prof. L. Bruner. Venis Mecas, Mex., Palmer (S. H. S.); Mexico, Botteri (S. H. S.). Since description I have received a male from Prescott, Arizona, collected by H. Edwards (Beutenmüller).

9. Scudderia furcata. Fig. 8.

Scudderia furcata Brunn., Mon. Phaneropt., 239, pl. 5, fig. 72 a (1878).
" " Blatchl.!, Proc. Ind. Acad. Sc., 1892, 101–102 (1894).
" " Beut.!, Bull. Amer. Mus. Nat. Hist., VI., 275 (1894).
" " Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 331, pl. 15, figs. 16, 17 (1897).
? *Gryllus* (*Locusta*) *myrtifolius* Drury [nec Linn.], Ill. Nat. Hist., II., 78, pl. 41, fig. 2 (1773).
Locusta myrtifolia Fabr., Syst. Ent., 282 (1775).
Phaneroptera curvicauda Burm.! [nec De Geer], Handb. Ent., II., 690 (1838).
Scudderia angustifolia Blatchl.! [nec Harr.], Proc. Ind. Acad. Sc., 1892, 102–103 (1894).
" " Beut.!, Bull. Amer. Mus. Nat. Hist., VI., 276 (1894).
Scudderia fasciata Beut.!, Loc. cit., VI., 276 (1894).

Stål, on study of Linné's type, finds his *Gryllus myrtifolius* (1758) to be a Ctenophlebia. Fabricius described his *Locusta myrtifolia* as the same, and Brunner accordingly quotes him in his synonymy of *Cten. myrtifolia;* but Fabricius' description ("anus maris lamina clavata, furcata") hardly allows this, and is very descriptive of the present species, to which it is also probable, but not so certain, that Drury's earlier figure from New York belongs.

I saw Burmeister's type of his *Phan. curvicauda* in the Berlin Museum more than thirty years ago, and made a drawing with notes of its characteristic anal segment; his description also applies well to this species only.

This is the most widely spread of any of the species of Scudderia, and appears to be tolerably common everywhere. The form *fasciata,* described as a distinct species by Beutenmüller, is one in which the principal longitudinal veins of the tegmina are marked heavily with fuscous, a feature repeated in several species of the genus.

Montreal, Canada, Lyman (S. H. S.). Maine (t. Brunner); Norway, Oxford Co. (M. C. Z., Morse); and Deering (Morse) and Brunswick, Packard (M. C. Z., S. H. S.), Cumberland Co., Me. White Mts., Valleys (S. H. S., Sprague), N. H. Brandon, Rutland Co., Vt., uplands (S. H. S.). Adams, Berkshire Co. (Morse); Princeton, Worcester Co. (S. H. S.); Beverly, Burgess (S. H. S.), and Gloucester (Sprague), Essex Co.; Sherborn (Morse), Cambridge (M. C. Z.), and

Malden (M. C. Z., Sprague), Middlesex Co.; Vicinity of Boston (M. C. Z., S. H. S.); Dover and Blue Hills (Morse), Wollaston and Dedham (Sprague) and Milton (M. C. Z., Sprague), Norfolk Co.; Seekonk, Bridgham (M. C. Z.), Bristol Co.; Scituate (Sprague), Plymouth Co.; Provincetown, Barnstable Co. (Morse); and Nantucket (S. H. S.), Mass. Kingston, Washington Co., R. I. (Morse). Connecticut, Norton (S. H. S.); Thompson, Windham Co.; New Haven; and Stamford, Fairfield Co. (Morse), Conn. Mt. Vernon, Westchester Co., Fitch (M. C. Z.) and Ithaca, Tompkins Co. (Morse), N. Y. New Jersey (t. Smith). Maryland, Uhler (S. H. S., M. C. Z.). Chillicothe, Ross Co., Ohio, Denton (Morse). Indiana (t. Blatchley). Northern Illinois, Kennicott (S. H. S.); Rock Island, McNeill (S. H. S.), and Port Byron, Rock Island Co., McNeill (S. H. S.); and Ogle Co., Allen (S. H. S.), Ill. Kentucky, Sanborn (M. C. Z.); Lexington, Fayette Co., Garman (S. H. S.), Ky. Virginia (Bruner). Carolina (t. Burmeister). North Carolina, Morrison (S. H. S.). Georgia, Morrison (M. C. Z.). Florida, Uhler (S. H. S.); and Jacksonville, Duval Co., Fla., Priddey (Bruner). Texas, Agassiz (M. C. Z.); Gulf Coast of Texas, Aaron (S. H. S.); Corpus Christi Bay, Palmer (S. H. S.); Waco, McLennan Co., Belfrage (S. H. S.); New Braunfels, Comal Co., Lincecum (S. H. S.); and Dallas, Boll (M. C. Z., S. H. S.), Texas. New Mexico, Meske (Bruner). Kansas (t. Bruner); Topeka, Shawnee Co., Shute (M. C. Z.); and West Point, Cuming Co. (Bruner), Nebr. Iowa City, Johnson Co., Shimek (Bruner), and Jefferson, Greene Co., and Dallas Co., Allen (S. H. S.), Iowa. Colorado, 5500′ and 6500′, Morrison (S. H. S.). Washington, Morrison (M. C. Z.). Hood River, Wasco Co., Portland, Multnomah Co., Drain and Roseburg, Douglas Co., Morse (Morse, S. H. S.), Oregon. Mt. Shasta district, Edwards (S. H. S.); Niles, Alameda Co., Woodworth (Morse); and Mendocino, Behrens (S. H. S.), California.

The form *fasciata* has been taken at Montreal, Ithaca, N. Y., Windham Co., Conn., and Virginia.

10. Scudderia septentrionalis. Fig. 9.

Phaneroptera septentrionalis Serv., Orth., 416 (1839).

Phaneroptera suturalis Heer, Insektenf. Tert. Oen., II., 4 (1849).

Phaneroptera curvicauda Scudd.! (pars) [nec De Geer], Bost. Journ. Nat. Hist., VII., 448 (1862).

Scudderia angustifolia Brunn. [nec Harr.], Mon. Phaneropt., 241 (1878).

Scudderia angustifolia Sauss.-Pict., Biol. Centr. Amer., Orth., 328, 329, 332 (1897).

Scudderia truncata Beut.!, Bull. Amer. Mus. Nat. Hist., VI., 252 (1894).

I think there can be little doubt that the *Phan. septentrionalis* of Serville is, as Brunner surmised, the species described by him under Harris' name *angustifolia*, and which has since been described by Beutenmüller as a new species under the name *truncata*. Serville's description will apply in most respects to the other species as well, but in three particulars it points to this: The small size, the length of the ovipositor of the female, and especially the lack of any mention of a pistillate anal segment in the male, while the subgenital plate is described with such particularity that had any process been present on the anal segment, it would surely have been mentioned in so formal a description; the case being quite different in Harris' popular description of his *angustifolia*. I am therefore constrained to restore Serville's name. The type does not exist in the Paris Museum, as I am kindly informed by Dr. Charles Brongniart, to whom I applied for particulars regarding it.

As regards Heer's *Phan. suturalis*, which has been completely overlooked, there can hardly be a doubt that it belongs here, for, after describing the subgenital plate, he goes on to say that the pistillate process of the anal segment seen in *curvicauda* is wanting ("an der Rückenplatte fehlt die vorn verbreitete zweilappige Verlängerung"), which is only true of the present species among the forms from the Eastern United States. His description, however, applies to a variety which may bear his name, *suturalis*, in which, as in some other of the species, the principal longitudinal veins of the tegmina carry a discolored stripe.

I must express a doubt whether the female described by Saussure and Pictet in the Biologia (from Panama?) belongs to this species; the measurements of the ovipositor indicate quite a distinct species. I add the measurements of a female from Massachusetts: Length of body, 20 mm. Pronotum, 5 mm. Tegmina, 26.5 mm. Middle breadth of same, 7.5 mm. Length hind femora, 18.5 mm. Ovipositor, 8.75 mm. Middle breadth of same, 2.5 mm.

Maine (t. Brunner); Norway, Oxford Co., Me., Smith (M. C. Z.). Mass. (S. H. S.); Wellesley, Norfolk Co. (Morse); and Seekonk, Bristol Co., Bridgham (M. C. Z.), Mass. Vineland, Cumberland Co., N. J. (Beutenmüller). Georgia (t. Heer). Chiriqui and Bugaba, Panama (t. Saussure and Pictet, — but see last paragraph, above).

11. Scudderia forcipata. Fig. 10.

Scudderia forcipata Brunn., Mon. Phaneropt., 242 (1878).
" " Sauss.-Pict., Biol. Centr. Amer., 328, 329, 332–333, pl. 15, fig. 22, 23 (1897).

I have not seen this species, and copy the drawings in the Biologia. It was first recorded by Brunner from Mexico; and afterwards, more specifically, by Saussure and Pictet, from Cordova, Vera Cruz, and Tabasco. Only the male is known.

SYMMETROPLEURA Brunner.

Symmetropleura Brunn., Mon. Phaneropt., 245 (1878).

Symmetropleura is distinctively characterized by having all the femora spined beneath, and by a very narrow fastigium between the antennæ; there is no pistillate production of the anal segment of the male. It was founded upon three species, found widely separated in North and South America and Africa. The single species in our fauna was known only by the male, the anal segment of which resembles that of *Scudderia septentrionalis*.

Symmetropleura modesta.

Symmetropleura modesta Brunn., Mon. Phaneropt., 246 (1878).

Brunner's single specimen was a male and came from Carolina. I have a female from North Carolina. It differs in no respect from the brief description of the male, except that the whole pronotum is ferruginous. The ovipositor is rather short, abruptly upturned just beyond the base, the upturned portion feebly tapering, apically well rounded, the margins of the apical half distinctly crenulato-dentate. The following measurements may be given: Length of body, 20 mm. Pronotum, 3.75 mm. Tegmina, 25 mm. Middle breadth of same, 6 mm. Length of hind femora, 16.5 mm. Ovipositor, 5 mm. Middle breadth of same, 2 mm.

PLATYLYRA (πλατύς, λύρα), gen. nov.

Fastigium of vertex anteriorly compressed, but apically almost as broad as the first antennal joint, truncate, contiguous with the frontal fastigium. Pronotum with the disk subconcave, broadening from in front backward, the front margin feebly concave, the hind margin a little convex, the lateral lobes subvertical, angularly deflexed, especially behind, where there are distinct canthi, the front margin straight and vertical, the posterior angle strongly and broadly rounded. Tegmina subovate, the posterior margin beyond the anal area straight, the apex well rounded, the radial veins nearly straight, the first branch simple like the succeeding, and emitted far beyond the middle, all terminating near together near the lower outer angle of the tegmina; tympanum of male subovate, but little longer than broad, the sides strongly arcuate, crossed by a pair of strong veins; wings broad, no longer than the tegmina. All the femora unarmed beneath, the genicular lobe of hind femora with a pair of minute spines at apex. Mesosternum twice as broad as long, the lobes slight. Anal segment of male short, triangular, broader than long, with no appendix; subgenital plate of male of moderate length, depressed throughout, tapering, deeply and angularly emarginate at apex, and beyond the emargination fissate, the lobes thus formed feebly falcate at tip. Ovipositor a little longer than the pronotum, the lower margin strongly arcuate, the apex subacutangulate.

A single species is known, occurring on our Pacific coast.

Platylyra californica, sp. nov.

Green, the tympanum of the male tegmina testaceous, the canthi of pronotum posteriorly castaneous and the fore and middle legs more or less testaceous. Lateral lobes of pronotum broader than long, the lower anterior angle subrectangulate. Mesosternal lobes rather slight, rounded, erect or suberect; metasternal lobes small, bluntly triangular. Tegmina subcoriaceous, opaque, broadest in the middle of the basal two thirds, the tip well and equally rounded; wings of the same length as the tegmina, only the apical sixth of the humeral area subopaque. Legs very slender, but not very long; fore and middle tibiæ spined above on each margin. Anal segment of male broader than long, rounded triangular; cerci of male rather stout and cylindrical at base, but this portion only a little longer than broad, bearing a long, arcuate, and slightly tortuous, a little incurved, slightly compressed, pointed, corneous hook, at base half as broad as the base of the cerci; subgenital plate of male arcuate, rather long and broad, depressed, tapering in the basal half, but beyond subequal. Ovipositor slightly longer than the pronotum, rather broad, the upper margin arcuate at base but beyond straight, the lower margin strongly and subequally arcuate throughout, the apex subacutangulate, the margins apically rufous and rather delicately and briefly denticulate, the basal plica concolorous.

Length of body, ♂, 13 mm.; ♀, 15 mm. Pronotum, ♂, 4.5 mm.; ♀, 4 mm. Tegmina, ♂, ♀, 17.5 mm. Breadth of same in middle, ♂, ♀, 6 mm. Breadth of wings, ♂, 11 mm. Length of hind femora, ♂, 17 mm.; ♀, 16.5 mm. Ovipositor, 5 mm. Middle breadth of same, 2.3 mm.

2 ♂, 1 ♀. California; one from Mt. Wilson, 2400′, Altadena, Los Angeles Co.; July 27, A. P. Morse; the others with no special locality.

I am indebted to Messrs. Samuel Henshaw, A. P. Morse, and F. S. Sprague for the loan of much material, principally from New England; to Messrs. W. S. Blatchley of Indiana and William Beutenmüller of New York for the opportunity of examining the species described by them; to Prof. Lawrence Bruner of Nebraska for a set of the species known to him; and to Hofrath Brunner von Wattenwyl for replies to many inquiries. My friend Mr. Henshaw has further aided me in a variety of ways with the specimens in the Museum of Comparative Zoology and the Boston Society of Natural History.

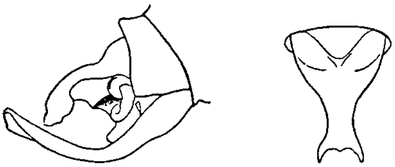
In the course of this study I have examined more than 650 specimens of the genus Scudderia alone.

EXPLANATION OF THE PLATE.

The drawings were made by Mr. J. W. Folsom, and, excepting the last, represent the lateral view of the extremity of the abdomen of the male, and a dorsal view of the anal segment, both enlarged.

Fig. 1. Scudderia texensis.
“ 2. “ pistillata.
“ 3. “ curvicauda.
“ 4. “ laticauda.
“ 5. “ mexicana.
“ 6. “ ungulata.
“ 7. “ furcifera.
“ 8. “ furcata.
“ 9. “ septentrionalis.
“ 10. “ forcipata. The end of the male abdomen from above; and the subgenital plate from below. Copied from the Biologia.

SCUDDER. — SPECIES OF SCUDDERIA.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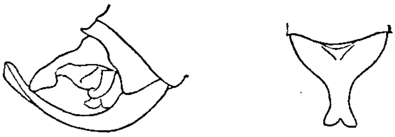
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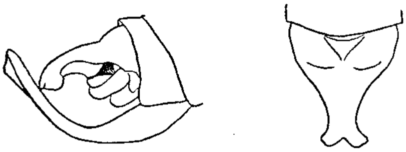
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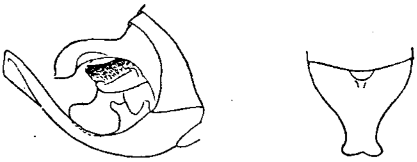
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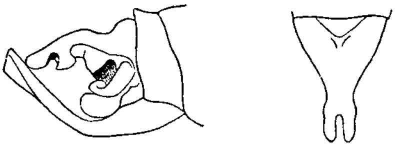
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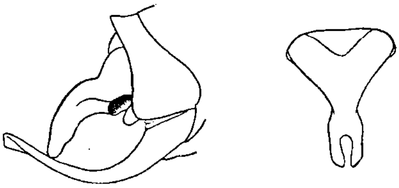
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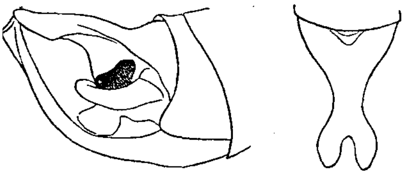
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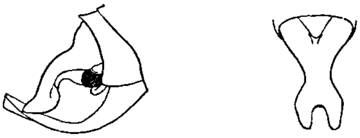
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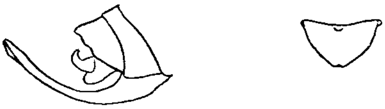
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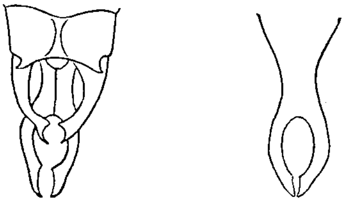
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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A TABLE OF ATOMIC WEIGHTS.

By Theodore William Richards.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF
HARVARD COLLEGE.

A TABLE OF ATOMIC WEIGHTS.

By Theodore William Richards.

Presented March 9, 1898.

Since no natural constants are more used by chemists than the atomic weights, it is a matter of great importance for every one, from the chemical philosopher to the practical analyst, to have a convenient table of them always at hand. Unfortunately the present state of our science makes the selection of the values often a matter of personal opinion; and because this is the case, it is well that many of those who have had experience in accurate quantitative analysis should express their views. Hence arose the present work, which was begun solely for use in Harvard College.

It is true that an accurate table of atomic weights may sometimes be less appropriate for the calculation of analyses than an inaccurate one. For the constant errors of any one process are eliminated as much as possible from the accurate table, and, moreover, all the results are reduced to the vacuum standard. Of course neither of these refinements is to be expected in common work, although many uncorrected methods may yield results which are very consistent among themselves. Obviously the best table for the practical calculation of analyses would be a list of factors, in which each quantity had been found empirically according to precisely the method which is to be employed in the analysis of an unknown substance.* Since, however, the errors of ordinary work often eliminate one another, and since such a table of empirical factors would have to be accompanied by exceedingly minute directions, the scientifically accurate table of atomic weights is generally the most convenient substitute for the factors demanded by the analyst, as well as the most suitable basis for theoretical considerations concerning the periodic system of the elements.

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* Compare Seubert, Berichte d. d. chem. Gesell., XXI. 2180.

In the compilation of the following table the chief emphasis has been laid on the probable chemical accuracy of the processes involved in each case. The search for possible causes of constant chemical error has usually furnished the evidence, if any evidence was to be obtained, upon which has been based the sometimes very puzzling decisions between conflicting data. For example, the possible occlusion of foreign matters by many precipitates has always been borne in mind, as well as the fact that crystals obtained from aqueous solutions usually retain with great obstinacy important amounts of mother liquor enclosed within their structure. Oxides and other substances obtained by ignition often have a tendency to occlude traces of other materials remaining from their mother compound; of course the possibilities of such a serious error must be carefully weighed in each case. Most experimenters upon the volumetric ratio of silver to the chlorides have produced erroneous data, through lack of knowledge of the dangers of this apparently simple process. These results must then be given small weight, no matter how concordant they may seem. The solubility of glass and porcelain, as well as of nearly all precipitates, is another frequently overlooked source of grave complications, and so is the action of many substances upon their containing vessels at high temperatures. The fact that in some cases the necessary methods of calculation greatly magnify the experimental error was not forgotten. These and many other equally obvious minor principles have served as the guides in the selection of the figures below; but of course the results cannot be considered ultimate. "Post-mortem examinations are often unable to detect the more subtle poisons." In many cases much more experimental work is needed, not only to secure new data, but also to show where the old are in error. While, however, it is very important to show such falsity, the attempt to counteract it numerically by the application of small corrections is a dangerous remedy; for minor conditions often seriously modify the minor corrections. In such cases wholly new data must usually be obtained, and these must be corrected, if correction is necessary, by him who is familiar with every step of the processes involved.

One is continually reminded, as he studies the conflicting evidence, of the words of Ostwald: "Differenzen sind nicht selten, und mahnen ernstlich an die Unvollkommenheit menschlicher Arbeit, aber auch an die Verantwortung, welcher jeder übernimmt, welcher einen numerischen Wert der Oeffentlichkeit mitteilt." * This responsibility is not always

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* Zeit. phys. Chem., III. 143.

ealized by eager investigators, who seek to make up for a possible lack of quality by a superabundance of quantity. "A single determination, well worked out, is better than twenty incomplete ones. Too much cannot be said against the multiplication of incomplete or carelessly obtained data; for such data carry with them not only uncertainty and confusion in the present, but also additional labor for a reviser in the future." * Every reaction must be assumed to involve some constant error, and every substance must be assumed to contain some constant impurity, until a proof of the contrary is obtained. Our wofully discordant data furnish a heavy presumption against almost any chemical method, when greater accuracy than one part in four or five hundred is desired.

The standard $O = 16.000$ is adopted below, as likely to be the most convenient for many years to come.† The last figure of each number given in the following table cannot be considered in any case certain. It is often probably not much more than one unit in error; although the uncertainty may amount to as much as six or eight units in some cases. Of course the decimal notation does not admit of closer indications without an individual explanation in each case. For example: iron, germanium, and gallium are given in the table as 56.0, 70.0, and 72.5 respectively. The first is probably known within 0.1 or 0.2, while the other two may easily be 0.5 in error; but the method of expressing the results does not admit of this grade of distinction.

The aim has been to construct a convenient working table, which shall carry with it all that is trustworthy, and nothing that is unnecessary. It is almost needless to state that the well known standard works of Clarke, Meyer and Seubert, Ostwald, Van der Plaats, and others, have been freely consulted in the preparation of this table, as well as many of the original papers.

Especially am I indebted to Professor Clarke for his last gigantic collection of data and results,‡ which would have made the present table a work of supererogation, if he had viewed the subject from a somewhat less mathematical standpoint. Professor Clarke's method of decision places the credit with the skilful manipulator; I have striven to give the thoughtful chemist who is not so clever with his hands the credit which I think belongs to him. The fact that the two tables usually agree is due either to the best method's having fallen into the best hands; or to Professor Clarke's having wisely forsaken the rigid application of his

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* These Proceedings, XXXI. 99; XXVI. 294.

† Compare F. W. Küster, Zeit. Anorg. Chem., XIV. 251.

‡ Smithson. Misc. Coll., Constants of Nature, V. (1897.)

principle; or else, especially in the case of the rare metals, to the lack of data affording room for intelligent difference of opinion. Among the seventy-four atomic weights given in the table, only seven differ enough from the values computed by Clarke to excite remark. It seems fitting to give a brief statement of the reasons for the differences in these seven cases, leaving the details of reasoning about the other sixty-seven elements unpublished. The elements mentioned are antimony, cadmium, calcium, magnesium, platinum, tungsten, and uranium.

It is not my purpose to enter at length into the discussion of the antimony problem. Much of the voluminous work upon this subject is now rejected by common consent. The work of Bongartz,* sometimes accepted as the best because it is the most recent, has the grave faults inherent in all methods which involve the precipitation of baric sulphate. Among all the published data Cooke's analyses of antimonious bromide † (Sb = 119.92) seem to me the most satisfactory, because of the admirable fitness of argentic bromide for quantitative work, and because of the many precautions used in both preparation and analysis. Cooke's † and Schneider's ‡ work upon the sulphide (Sb = 120.5) are perhaps the next in order; but Cooke's work upon this subject was far less satisfactory than his work on the bromide. Accordingly, the value 120.0 is given as the atomic weight of antimony in the accompanying table, instead of 120.43, computed by Clarke.

Although the atomic weight of cadmium has been the subject of many investigations, it is still far from certainly established. Many reasons combine to make me think that the highest of the published values are the most accurate. Dumas's § work upon the chloride of cadmium led to the value 112.23; but his method of investigating chlorides sometimes gave him too low results.‖ V. Hauer ¶ and Partridge ** found cadmium equal to less than 112 by heating cadmic sulphate in a stream of hydric sulphide, but there is no proof that their initial substance was thoroughly dried. On the other hand, Bucher's conversion of cadmic sulphate into the oxide led to the value 112.36, which Bucher regards as the minimum.* This method is one in which the tendency of the oxide to retain sulphuric acid is approximately neutralized by the tendency of the sulphate to retain water; this fact, which is testified by Baubigny's † good results on zinc, nickel, and aluminium, as well as Marignac's on magnesium.‡ The results of Lenssen,§ Partridge, Morse and Jones,‖ and Bucher, involving the use of cadmic oxalate, all in the neighborhood of 112, are likely to be too low because of the great difficulty of freeing this substance from water. Morse and Jones have clearly indicated this and other possible causes of error. Moreover, I doubt very much if it is possible to prepare the oxalate free from the nitrate by precipitation from solutions containing cadmic nitrate. The method of calculation magnifies either error by introducing it in opposite directions into the numerator and denominator. Bucher's extended work casts grave doubt upon cadmic oxide (used by Morse and Jones, and Lorimer and Smith ¶) as a suitable substance to serve for a basis of operations. On the other hand, the work of Huntington ** and Bucher with the bromide (a very satisfactory substance as to its preparation because it may be sublimed, and as to its analysis because of the insolubility of argentic bromide), and that of Bucher with cadmic chloride, point toward 112.3 or 112.4 as the probable figure. The electrolytic work of Hardin †† upon these compounds, performed unfortunately with small amounts of material, is nevertheless in favor of the lower value, 112.0; so that any value adopted must be uncertain. Clarke computes 111.95; for the following table 112.3 has been chosen.

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* Bongartz, Berichte d. d. chem Gesell., XVI. 1942. (1883.)

† Cooke, Proc. Am. Acad., V. 13. (1877.)

‡ Schneider, Pogg. Ann., XCVIII. 293 (1856); Journal prakt. Chem., (2), XXII. 131. (1880.)

§ Dumas, Ann. Chem. Pharm., CXIII. 27. (1860.)

‖ See these Proceedings, XXX. 371. Cases in point: barium, strontium, sodium, and tin.

¶ Von Hauer, Journ. prakt. Chem., LXXII. 350. (1857.)

** Partridge, Am. Journ. Sci., (3), XL. 377. (1890.)

There is good reason for believing that Clarke's value for calcium (40 07) is probably too high The only determinations worth considering are those of Erdmann and Marchand upon the composition of Iceland spar, and only one out of their thirteen experiments is corrected for known causes of constant error.‡‡ This experiment, which really constitutes the sum and substance of our pseudo-accurate knowledge of a very important quantity, makes calcium almost exactly 40.0.

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* J. E. Bucher, Johns Hopkins Inaug. Dissertation, Baltimore. (1892.)

† Baubigny, Compt. Rend., XCVII. 906, 951, 1369. (1883.)

‡ Marignac, see under magnesium, later in this paper. Compare These Proceedings, XXVI. 260, 273; XXXI. 160.

§ Lenssen, Journ. prakt. Chem., LXXIX. 281. (1860.)

‖ Morse and Jones, Am. Chem. Journ., XIV. 260.

¶ Lorimer and Smith, Zeit. Anorg. Chem., I. 364.

** These Proceedings, (1881,) p. 28.

†† Hardin, Journ. Am. Chem. Soc., XVIII. 1016. (1096.)

‡‡ Erdmann and Marchand, Journ. prakt. Chem., L. 237. (1850.)

Obviously but little confidence may be placed in such meagre material; it is surprising enough that so common an element has remained forty years untouched on so unsatisfactory a basis. An extended investigation, now well advanced in this Laboratory, has as its object the securing of less impeachable data upon the atomic weight of this frequently appearing constituent of the universe.

Marignac's* results from the quantitative ignition and synthesis of magnesic sulphate, processes in which the constant errors are likely to eliminate one another, have been so completely confirmed by the recent work of Richards and Parker,† that magnesium is represented by the figure 24.36 in the table. The results of the syntheses of magnesic oxide by Burton and Vorce ‡ have been shown by Richards and Rogers § to be under the cloud of a serious possible constant error, and no other results offer weighty evidence against the value just named.

An important deviation from the usually accepted figures is to be seen in the value assigned to platinum below. Our knowledge of the atomic weight of this element depends chiefly upon the elaborate and carefully executed work of Seubert ‖ and Halberstadt,¶ and the only question is how this is to be interpreted. These chemists studied the platinchlorides and platinbromides of potassium and the platinchloride of ammonium, weighing these compounds and some of the products of their decomposition. The careful study of the results shows at once that some source of error lies hidden in all the data, for the various ratios are not wholly consistent, even in any one series. Any value from 194.7 to 196. may be obtained from the figures,** the results of Seubert's work being the least discordant among themselves. Dittmar and M'Arthur †† explain the discrepancies in the case of potassic platinchloride by assuming that the complex salt contains traces of hydroxyl replacing the halogen and traces of hydrogen replacing the potassium, as well as a small amount of extra occluded potassic chloride. They adduce experimental evidence in proof of this view, but Seubert showed in his reply * that their hypotheses can hardly be applied to his determinations. Most of Seubert's and Halberstadt's inconsistencies may be explained by the supposition that the complex salts, like all substances crystallized from aqueous solution, contain traces of mother liquor held in minute cells within the crystal structure, and that these traces of water are not set free until the substance is disintegrated. I have accumulated a large amount of experimental evidence, soon to be published, upon this subject. Water is one of the most dangerous, although one of the least heeded, impurities in this kind of work; and in my opinion it is responsible for the lack of agreement in this case. Hence the best data for the calculation of the atomic weight of platinum seem to be those concerning the relation of the metallic platinum to the potassic chloride or potassic bromide formed by the decomposition of the complex salts; for the water must surely have been expelled from these products of the ignition. According to Clarke † potassic platinchloride yields 40.101 per cent of platinum and 30.671 per cent of potassic chloride, — the means of the closely agreeing results of Seubert and Halberstadt, — while according to Halberstadt potassic platinbromide yields 25.915 per cent of platinum and 31.591 per cent of potassic bromide. Disregarding the weight of the complex salt, and assuming that $KCl = 74.595$, and $KBr = 119.095$, it is easy to calculate the respective values 195.06 and 195.39 for platinum. The mean of these two values, 195.2, is given below, instead of Clarke's 194.89. The possible occlusion of potassic halide by the complex salt may render even 195.2 too low; but more investigation is evidently needed to prove this.

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* Marignac, Arch. Sci. Phys. et Nat., (3), X. 206.

† Richards and Parker, These Proceedings, XXXII. 53; Zeit. Anorg. Chem. XIII. 81. (1896.)

‡ Burton and Vorce, Am. Ch. Journ., XII. 219. (1890.)

§ Richards and Rogers, These Proceedings, XXVIII. 200.

‖ Seubert, Ber. d. d. chem. Gesell., XIV. 865. (1881.)

¶ Halberstadt, Ibid., XVII. 2962. (1884.)

** Clarke, Recalculation, (1897,) p. 334.

†† Trans. Roy. Soc. Edinburgh, XXXIII. Part II. 561. (1887.)

The same errors may enter into the work on other platinum metals; indeed Seubert ‡ admits that traces of water were contained in some of his salts, but he applies no correction for this serious cause of inaccuracy. Since, however, Clarke's method of combining the discordant results seems more nearly to eliminate the error in these cases, his values for these elements are but little changed in the following table.

Feeling wholly unable to decide the present controversy between the two conflicting values (184.9 and 184.0) now proposed for tungsten, I have chosen the mean, 184.4, as a compromise which cannot be much more than 0.3 per cent out of the way.§

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* Berichte d. d. chem. Gesell., XXI. 2179.

† Recalculation, page 333.

‡ Liebig's Annalen, CCLXI. 262.

§ Compare Hardin, Journ. Am. Ch. Soc., XIX. 657. (1897.)

Uranium, the highest of all the atomic weights, is one of the least satisfactorily determined. Recent investigation upon this subject at Harvard seems to show that all the published data are complicated by constant errors, which, however, sometimes partly eliminate one another; accordingly the round number 240, instead of Clarke's 239.59, is printed in the table. The discussion is better deferred until our work has taken more definite shape.

Besides these seven elements, there are seventeen more whose atomic weights, as given in the following table, differ from the results of Professor Clarke's computations by one part in a thousand or more. As none of the seventeen values is known certainly to within one part in five hundred, and some of them are probably at least as much as one per cent in error, differences in these cases will excite no especial remark. The elements are: cerium, columbium, erbium, gadolinium, gallium, glucinum, indium, lanthanum, neodymium, osmium, palladium, praseodymium, samarium, scandium, thorium, ytterbium, and zirconium. This is by no means a complete list of the uncertain elements, but only of those for which the data admit of slightly different interpretations.

It is rather unfortunate that most classified tables of the elements omit the fractional parts of the atomic weights, for these fractions will undoubtedly play an essential part in the ultimate solution of the de-Chancourtois-Newlands-Mendeléev-Meyer mystery. In order to present a modern table which will supply these omissions, as well as afford at a glance an approximate idea of the probable error in each case, I have repeated the values in the natural order. From the classified table have been omitted several elements whose atomic weights and properties are uncertain; their presence in the system serves rather to obscure well known relations than to elucidate new ones. That this procedure is an admission of incompleteness is evident; the last part of the table is at best a lame affair. The form proposed by Thomsen * is perhaps the most generally satisfactory of the current modes of arrangement, but his last row is unwieldy both for printing and for thinking. In the accompanying table a compromise has been adopted which cannot fail to be comprehensible; it is not my purpose here to enter into the arguments regarding the adequacy of the various forms.

This table will be reprinted, with any changes which may be necessary, every year. Since the commencement of the work I have been glad to hear of the appointment of a committee by the German

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* Zeit. Anorg. Chem., IX. 190.

Chemical Society to accomplish a similar purpose, the American Chemical Society having for several years possessed such a committee. The matter cannot receive too much intelligent examination.

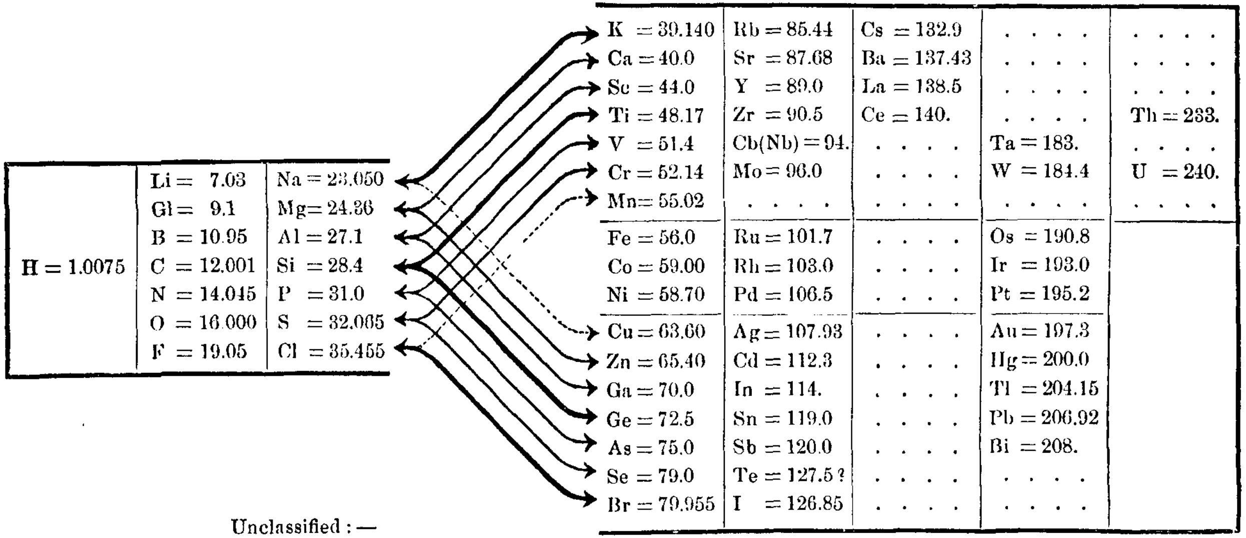
A TABLE OF ATOMIC WEIGHTS

OF SEVENTY-FOUR ELEMENTS.

Compiled in March, 1898, *from the most Recent Data.*

Name.	Symbol.	Atomic Weight.	Name.	Symbol.	Atomic Weight.
Aluminium	Al	27.1	Molybdenum	Mo	96.0
Antimony	Sb	120.0	Neodymium	Nd	141.
Argon	A	39.9 ?	Nickel	Ni	58.70
Arsenic	As	75.0	Niobium	Nb = Cb	94.
Barium	Ba	137.43	Nitrogen	N	14.045
Beryllium	Be = Gl	9.1	Osmium	Os	190.8
Bismuth	Bi	208.	Oxygen (standard)	O	16.000
Boron	B	10.95	Palladium	Pd	106.5
Bromine	Br	79.955	Phosphorus	P	31.0
Cadmium	Cd	112.3	Platinum	Pt	195.2
Cæsium	Cs	132.9	Potassium	K	39.140
Calcium	Ca	40.0	Praseodymium	Pr	144.
Carbon	C	12.001	Rhodium	Rh	103.0
Cerium	Ce	140.	Rubidium	Rb	85.44
Chlorine	Cl	35.455	Ruthenium	Ru	101.7
Chromium	Cr	52.14	Samarium	Sm	150.
Cobalt	Co	59.00	Scandium	Sc	44.
Columbium	Cb = Nb	94.	Selenium	Se	79.0
Copper	Cu	63.60	Silicon	Si	28.4
"Didymium"	Nd + Pr	142 ±	Silver	Ag	107.93
Erbium	Er	166.	Sodium	Na	23.050
Fluorine	F	19.05	Strontium	Sr	87.68
Gadolinium	Gd	156. ?	Sulphur	S	32.065
Gallium	Ga	70.0	Tantalum	Ta	183.
Germanium	Ge	72.5	Tellurium	Te	127.5
Glucinum	Gl = Be	9.1	Terbium	Tb	160.
Gold	Au	197.3	Thallium	Tl	204.15
Helium	He	4.0 ?	Thorium	Th	233.
Hydrogen	H	1.0075	Thulium	Tu	170.?
Indium	In	114.	Tin	Sn	119.0
Iodine	I	126.85	Titanium	Ti	48.17
Iridium	Ir	193.0	Tungsten	W	184.4
Iron	Fe	56.0	Uranium	U	240.
Lanthanum	La	138.5	Vanadium	V	51.4
Lead	Pb	206.92	Ytterbium	Yb	173.
Lithium	Li	7.03	Yttrium	Yt	89.0
Magnesium	Mg	24.36	Zinc	Zn	65.40
Manganese	Mn	55.02	Zirconium	Zr	90.5
Mercury	Hg	200.0			

THE CLASSIFICATION OF THE ELEMENTS.



H = 1.0075	Li = 7.03	Na = 23.050
	Gl = 9.1	Mg = 24.36
	B = 10.95	Al = 27.1
	C = 12.001	Si = 28.4
	N = 14.045	P = 31.0
	O = 16.000	S = 32.065
	F = 19.05	Cl = 35.455

K = 39.140	Rb = 85.44	Cs = 132.9	. . . .	. . . .
Ca = 40.0	Sr = 87.68	Ba = 137.43	. . . .	. . . .
Sc = 44.0	Y = 89.0	La = 138.5	. . . .	. . . .
Ti = 48.17	Zr = 90.5	Ce = 140.	. . . .	Th = 233.
V = 51.4	Cb(Nb) = 94.	. . . .	Ta = 183.	. . . .
Cr = 52.14	Mo = 96.0	. . . .	W = 184.4	U = 240.
Mn = 55.02	. . . .	. . . .	. . . .	. . . .
Fe = 56.0	Ru = 101.7	. . . .	Os = 190.8	
Co = 59.00	Rh = 103.0	. . . .	Ir = 193.0	
Ni = 58.70	Pd = 106.5	. . . .	Pt = 195.2	
Cu = 63.60	Ag = 107.93	. . . .	Au = 197.3	
Zn = 65.40	Cd = 112.3	. . . .	Hg = 200.0	
Ga = 70.0	In = 114.	. . . .	Tl = 204.15	
Ge = 72.5	Sn = 119.0	. . . .	Pb = 206.92	
As = 75.0	Sb = 120.0	. . . .	Bi = 208.	
Se = 79.0	Te = 127.5 ?	. . . .	. . . .	
Br = 79.955	I = 126.85	. . . .	. . . .	

Unclassified: —

Helium = 2.0 or 4.0 ?
Argon = 19.94 or 39.9 ?
Neodymium = 141.
Praseodymium = 144.
Samarium = 150.
Gadolinium = 156.
Terbium = 160.
Erbium = 166.
Thulium = 170.
Ytterbium = 173.

Anomalous: —

Cobalt = 59.00
Nickel = 58.70
Tellurium = 127.5

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CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY.

New Series. — No. XIII.

By B. L. Robinson.

I. Revision of the North American and Mexican species of *Mimosa*.

II. Revision of the North American species of *Neptunia*.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, No. XIII.

By B. L. Robinson.

Presented March 9, 1898.

I. — REVISION OF THE NORTH AMERICAN AND MEXICAN SPECIES OF MIMOSA.

The greater part of our North American species of Mimosa barely attain our southwestern borders. They are the northernmost representatives in the New World of a large and difficult chiefly tropical group, and their affinities must accordingly be sought among more southern forms. In revising for the *Synoptical Flora* the North American species of the genus, the writer has, therefore, been constantly compelled to trace their southward extension and study their relationships among the Mexican and even Central American species. This has necessitated the examination of critical and imperfectly identified material to such an extent, that a general revision of the Mexican and Central American, as well as the North American species, has seemed the simplest solution of the difficulties. Bentham's well-known monograph * of the genus, — which must always stand as one of the classics of botanical taxonomy, — is as clear and excellent as ever, but has become somewhat antiquated by nearly a quarter of a century of unprecedented activity in exploration. The large and rich collections of Messrs. Pringle, Palmer, J. Donnell Smith, Nelson, Rose, Brandegee, Millspaugh, L. C. Smith, C. L. Smith, Pittier, Conzatti, Dugès, Hartman, and Lloyd, are all of later date. They have added a wealth of new material, but it has been identified at different times and places and, as is natural, with varying degrees of accuracy; so that in this, as in every other large group, the true results of modern exploration can only be brought to light by revision and monographic study. The specimens cited in the following synopsis are chiefly those of recent collectors, and little effort has been made to repeat the older citations of specimens and localities, which are duly recorded in Hemsley's Biol. Cent. Am. Bot.

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* Trans. Linn. Soc. xxx. 388–441.

Wherever possible, Bentham's paper, the result of more than thirty years' study of the genus, has been taken as a basis of arrangement. But his series of *Rubicaules* seems an unfortunate and artificial aggregation of species without close affinities. Several of these are here placed with the *Schrankioideæ*, and *M. Berlandieri* is referred to what is believed to be its natural position as a variety of *M. asperata*. It is doubtful whether Bentham ever saw *M. Ervendbergii*. At all events he did not recognize what is now evident, namely, that it was founded upon two distinct plants.

The construction of a satisfactory key to the species of *Mimosa* is well nigh impossible. Except in the number of their stamens the flowers are too uniform to furnish many good characters. The inflorescence passes gradually from capitate to spicate, the number of leaflets varies astonishingly upon the same individual, and the spines are singularly inconstant, being well developed or obsolete in plants which appear in all other respects identical. Therefore the key here offered, although the result of considerable study and experimentation, must be used with due caution. *M. albida*, *acanthocarpa*, and *biuncifera* appear to be the types of polymorphous aggregates of intergrading forms. Aside, however, from these species and several of their close allies, the species within the limits of the present paper are pretty clearly marked and show little tendency to intergrade.

Besides the material in the Gray Herbarium, the writer has been kindly permitted to examine and borrow from the material of *Mimosa* in the Herbarium of the N. Y. Botanical Garden. Mr. John Donnell Smith has lent his rich representation of the Central American *Sensitivæ*, and Dr. J. N. Rose of the U. S. National Museum, has sent for examination a large number of most interesting forms from Mexico, collected chiefly by himself and Mr. Nelson, and containing several new and well marked species. Further material has also been sent to the writer from Lower California by Mr. and Mrs. T. S. Brandegee, from Honduras by Dr. Gustavo Niederlein and from New Mexico by Miss Mulford. Upon request several specimens have been examined and compared by the staff of the Royal Gardens at Kew. For all of these favors, which have contributed much to the completeness of the present revision, the writer here expresses grateful appreciation.

The generic limits ascribed to *Mimosa* in this paper fully coincide with those of Bentham and other recent writers, so that it is needless to repeat here the well-known generic characters. A word may be said regarding the derivation of the name. At least it may be stated that no satisfactory etymology has thus far been suggested. The traditional derivation from *mimus*, a mimic actor, which has for many years been handed down in our text-books, was early given by Tournefort. The name, however, dates back of Tournefort, and his explanation is in several regards unsatisfactory. In the first place no ordinary rules of word-composition would lead to the formation of a Latin substantive ending in *osa* from another ending in *us*. Nor if such derivation could be accomplished does it explain the traditionally long *o* of the penultimate syllable. Prof. J. B. Greenough has suggested a possible connection with a theoretical (although never actually used) active participle *μιμοῦσα* from *μιμέομαι*. Further light upon this subject is desired, but the writer has not had an opportunity to follow the matter historically beyond a few of the more accessible works. Any derivation from *μιμώ*, an ape, seems also to offer philological difficulties.

No authentic specimen of the doubtful M. ARCUATA, Mart. & Gal., has been seen, but from the original description, Bull. Acad. Brux. x. pt. 2, 308, it would seem near to, if not synonymous with, *M. biuncifera*, Benth.

M. GEMINATA, DC. (Prodr. ii. 427; A. DC. Calques des Dess. t. 205), is wholly dubious.

Subg. 1. ASTATANDRA, n. subg. Flowers polygamous in the same head; staminate flowers with twice as many stamens as segments of the corolla; perfect flowers with stamens of the same number as the segments of the corolla.

1. **M. tequilana**, WATS. Low branching tawny-hirsute annual, armed with weak scattered spines: pinnæ 1 pair; leaflets one or two pairs upon each secondary rhachis,* obovate, rounded and mucronate at the apex, thin, sensitive, glabrous above, appressed-villous with tawny hairs beneath: flowers in small ovoid heads: corolla 3–4-toothed: calyx obsolete: legume armed on edges and valves with weak straight spreading spinescent bristles. — Proc. Am. Acad. xxii. 409 (1887). — Hillsides, Tequila, Jalisco, *Palmer*, no. 378, August to September, 1886, and in the same locality, *Pringle*, no. 4596. Placed in the *Modestæ* by Dr. Watson, who seems not to have noted the two kinds of flowers with differing andrœciums.

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* When the number of leaflets is given in this paper, it applies merely to those upon a single secondary rhachis, not to those of a whole leaf.

Subg. 2. EUMIMOSA, DC. (as modified by Benth.). Flowers perfect or polygamous: stamens in all equal in number to the lobes of the corolla. — Mém. Lég. xii. 418, & Prodr. ii. 425, in major part; Benth. Trans. Linn. Soc. xxx. 388, 389.

* Pinnæ 1 pair; leaflets very large, ovate or ovate-lanceolate to obovate, 1 or more commonly 2 pairs upon each secondary rhachis, but the inner leaflet of the lower pair mostly much reduced or even wanting. — Series *Sensitivæ*, Benth. l. c. 388, 390.

+ Stem glabrous or in *M. manzanilloana* slightly strigose.

++ Unarmed shrubs or trees.

2. **M. sesquijugata**, J. D. SMITH. Low shrub branched from the base: leaflets elliptic-oblong or lance-oblong, rounded or acutish at the apex, coriaceous and reticulate-veiny, glabrous and lucid above, appressed-setose but soon glabrate and glaucous beneath, 15 to 20 mm. long: petioles slender, essentially glabrous: peduncles downwardly strigose: flowers purplish, tetramerous. — Bot. Gaz. xiii. 74 (1888). — In rock-fissures near Santa Rosa, Dept. Baja Verapaz, Guatemala, altitude 1525 m., July, 1887, *von Tuerckheim* (no. 1327 of J. D. Smith's valuable Guatemalan set).

3. **M. Goldmanii.** Small tree, 3 to 6 m. high: glabrous throughout except for the setose-ciliate margins of the leaflets, stipules, and bracts: stems woody, covered with grayish brown bark: petioles filiform; leaflets obovate-oblong, obtuse or rounded, mucronate, rather thin, green above, perfectly glabrous and slightly glaucescent beneath, 12 to 18 mm. long, 6 to 8 mm. broad; margin ciliate with conspicuous appressed or incurved stramineous bristles; rhachises devoid of bristles; stipules subulate, attenuate, slightly ciliate: peduncles filiform, usually equalling or often exceeding the petioles, fascicled on short or undeveloped secondary axes; heads numerous, globose, 12 mm. in diameter; flowers 4-merous, purplish white: legume unknown. — Collected by *Nelson & Goldman* between Juchitan and Chivela, Oaxaca, at 50 to 275 m. altitude, 1895, no. 2628 (herb. Gray and herb. U. S. Nat. Mus.). This species differs from any of the other Mexican and Central American species of the *Sensitivæ* in its perfectly glabrous peduncles and petioles, also by having the lower surface of the leaflets devoid of setæ as well as any trace of pubescence. It is evidently near the South American *M. glaucescens*, Benth. and *M. angusta*, Benth., but these from description have larger leaflets and are woody only at the base.

++ Shrub, moderately armed with small scattered light-colored recurved spines: margin of legume bearing very short incurved bristles; valves strigillose and also finely pubescent.

4. **M. manzanilloana**, Rose. Branches sometimes slightly strigose, mostly glabrous, terete, slender, at length verrucose: leaflets oblong, acutish or obtusish and mucronate, glabrous above, setose on the edge and lower surface; petioles slender, glabrous, slightly armed: peduncles slender, 2.5 cm. or more in length: buds considerably exceeding the very small and inconspicuous bracts. — Contrib. U. S. Nat. Herb. i. 326. — Manzanillo, Mexico, December, 1890, *Palmer*, no. 905. Near the common *M. floribunda*, Willd., but essentially glabrous and of much more slender habit.

+++ Scandent shrub copiously armed with recurved more or less 4-seriate spines: margin of legume covered with long straight acicular bristles; valves glabrous.

5. **M. Velloziana**, Mart. Glabrous except for the strigose bristles of the stipules and leaflets: petioles stout, copiously armed with retrorse spines: peduncles short, 12 to 16 mm. in length: bracts in the young heads conspicuous, setose-ciliate, equalling or exceeding the buds. — Herb. Fl. Bras. 185, & Flora, xxii. pt. 1, Beibl. 9; Benth. Trans. Linn. Soc. xxx. 390. *M. viva*, Vell. Fl. Flum. Ic. xi. t. 33 (where leaflets are figured with too fine and copious pubescence), not L. — Isthmus of Panama, *Seemann*, no. 100 (in herb. Gray), and at Chagres, 19 February, 1850, *Fendler*, no. 91. Also, acc. to Hemsley, in pastures at Chojojo, near Mazatenango, Guatemala, *Bernoulli*, no. 60, and at Guanacaste, Costa Rica, *Oersted*. (Also S. Am.) No. 4133 of Captain J. D. Smith's distribution, collected at Malpais, Dept. Santa Rosa, Guatemala, and determined as this species by Micheli, differs in its less armed stems and petioles, longer peduncles, and inconspicuous floral bracts. It is undoubtedly distinct from *M. Velloziana*, but the specimen lacks fruit.

+ + Stem at least toward the apex covered with soft usually spreading as well as bristly pubescence or rarely in *M. floribunda* merely strigillose.

+ Slender, herbaceous or suffrutescent: leaflets obovate to oblong, rounded and mucronulate at the apex, appressed-villous or setulose upon both surfaces: legume copiously setose on valves and margin.

6. **M. debilis**, H. & B. Scarcely armed: pubescence fine, spreading: petioles long and slender, unarmed: pods copiously setose on margins and valves. — H. & B. in Willd. Spec. iv. 1029; Benth. l. c. 391. *M. notata*, Steud. Flora, 1843, 758, & *M. Hostmanni*, Benth. in Hook. Lond. Jour. Bot. v. 84, acc. to Benth. — Trop. S. Am.

Var.? panamensis, BENTH. Annual or a slender undershrub, armed with scattered recurved spines: leaflets oblong, narrower than in the typical form, the larger 18 mm. long, 6 mm. broad. — Trans. Linn. Soc. xxx. 391. — Panama, in meadows near Nata, *Seemann*, no. 98 (in herb. Gray); also at Boruca, Costa Rica, *Pittier*, no. 4554 (distrib. as *M. sensitiva*).

++ ++ Armed shrubs with ovate-lanceolate or ovate-oblong, acutely or at least bluntly pointed leaflets: margin of legume bearing long straight spreading spinescent bristles; valves sparingly covered with weak straight appressed bristles.

M. SENSITIVA, L. Spines of stem numerous (rarely few), somewhat 4-seriate, very short, recurved: petioles copiously armed; leaflets lanceolate, thickish, glabrous or puberulent above, appressed-setulose beneath. — Spec. i. 518 (Breyne, Cent. 31, t. 16); Benth. Trans. Linn. Soc. xxx. 390, & in Mart. Fl. Bras. xv. pt. 2, 305. — Brazil, *Claussen* (Mart. Herb. Fl. Bras.) 1079 (in herb. Gray). This S. American species has been credited to Costa Rica by Micheli (Bull. Soc. Bot. Belg. xxx. 294) on the basis of Pittier's nos. 23, 1279, 1279 bis, 1447, 1448, 3013, but the writer, who (through the kindness of Captain J. Donnell Smith) has seen specimens of all these numbers except 1448, would regard them as mere forms of *M. albida*, H. & B.

++ ++ ++ Armed shrubs with leaflets mostly acutish but sometimes rounded at the apex: legumes finely strigillose with short appressed or often incurved hairs both on margin and valves.

7. **M. albida**, H. & B. A polymorphous species: stems armed with scattered (not seriate) spines, and covered with spreading usually copious often tawny hairs: leaflets acutish rarely obtuse or rounded, covered on both surfaces with fine white appressed hairs which are denser and often mixed with strigose bristles beneath: pedunculate heads axillary or aggregated in long terminal almost naked racemes. — H. & B. in Willd. Spec. iv. 1030; Kunth, Mimos. 2, t. 1. *M. sensitiva*, Lodd. Bot. Cab. t. 249; Micheli, Bull. Soc. Bot. Belg. xxx. 294; not L. — S. Mexico and Centr. Am., southward to Peru. San Luis Potosi, *Pringle*, no. 3970; Sinaloa, *Rose*, no. 1731 (peculiar form with broad very obtuse leaflets); Jalisco, *Palmer*, no. 693 (coll. of 1886); Orizaba, *F. Müller*, no. 172, *Bourgeau*, no. 2861; Oaxaca, *Nelson*, nos. 792, 2070, *L. C. Smith*, no. 792; Vera Cruz, *Nelson*, nos. 63, 479; Huasteca, *Ervendberg*, no. 1; Guatemala, *Hayes*, *J. D. Smith*, nos. 300, 2307, 6118 (in part passing to var. *floribunda*); Costa Rica, *Oersted* no. 10, *J. D. Smith*, nos. 5765, 8975, *Pittier*, nos. 23, 1279, 1279 b, 1447, 3013,

Tonduz, no. 1568; Honduras, *J. D. Smith*, no. 5215, *Niederlein*. In a considerable series of specimens it has been impossible to find any constant or satisfactory characters or combinations of characters to separate this species from the following forms here included as varieties. The differences of pubescence, which are striking in extremes, undergo the most gradual and complete intergradation and appear to be correlated with no other important distinctions. It is probable that all the forms here given cross freely when occurring in the same region.

Var. **strigosa** (*M. strigosa*, Willd. l. c.). Leaflets acutish, beset upon both surfaces with coarser strigose hairs. — Costa Rica, *Oersted*, no. 8.

Var. **floribunda** (*M. floribunda*, Willd. l. c. 1031). Leaflets acutish, glabrous above, covered below with appressed setæ: pedunculate heads mostly collected in almost naked terminal racemes: corolla puberulent to tomentulose. — Jalisco, *Palmer*, no. 705 (coll. of 1886); Orizaba, *Botteri*, no. 569, *Seaton*, no. 141; Vera Cruz, *Bourgeau*, no. 1541, *C. L. Smith*, nos. 1142, 1716, 1719, *Nelson*, nos. 72, 160; Puebla, *Nelson*; Guatemala, *Hayes*, *J. D. Smith*, no. 3308. Captain Smith's no. 5764 from Costa Rica, and Kerber's nos. 119 and 353 from S. Mexico are good examples of transitions between *M. albida* and its var. *floribunda*. It is probable also that leaflets which are at first pubescent above are sometimes glabrate in age.

Var. **euryphylla**. Scarcely armed: leaflets broad, obovate, rounded and merely mucronulate at the apex, glabrous and somewhat lucid above, appressed-villous beneath: corolla glabrous. — Collected by *E. W. Nelson* in the valley of Jiquipilas, Chiapas, altitude 675 to 850 m., 16 to 18 August, 1895, no. 2927 (in herb. U. S. Nat. Mus.).

Var. **glabrior**. Stem and branches nearly glabrous: leaflets acute or acutish, glabrous above, sparingly setose beneath: corolla glabrous. — *M. Velloziana*, Micheli in J. D. Smith, Pl. Guatem. &c. iv. 49, not Mart. — Coll. *Heyde* & *Lux* at Malpais, Dept. Santa Rosa, Guatemala, altitude 1230 m., no. 4133 of J. D. Smith's distrib.

* * Pinnæ 1 to several pairs; leaflets 3 to several pairs, smaller.

+ Stems herbaceous (sometimes becoming slightly ligneous in *M. pudica*), hirsute with spreading often tawny hairs; pinnæ 1 or 2 (closely approximated) pairs.

++ Leaflets ovate or obovate: fruit finely pubescent upon the valves.

8. **M. Skinneri**, Benth. Low, much branched hirsute annual: leaves with 2 or 4 digitately arranged secondary rhachises; leaflets obovate, 3 to 8 pairs, crowded, obtuse, very sensitive, glabrous above, appressed tawny-villous below: infra-stipular spines stramineous, straight:

legume about 3-jointed, finely pubescent upon the valves and strongly setose on the margin. — Benth. in Hook. Lond. Jour. Bot. v. 85, & Trans. Linn. Soc. xxx. 392. — Borders of Oaxaca and Chiapas, *Nelson*, no. 2858; Guatemala, *Skinner*, acc. to Benth., *J. D. Smith*, nos. 3758, 6132; Costa Rica, Ujaras, *Oersted*, acc. to Hemsl.

9. **M. Pittieri**, Micheli. Pinnæ always 2 pairs; leaflets 5 to 6 pairs, ovate, ciliate: infra-stipular spines recurved, caducous: peduncles axillary, solitary, exceeding the petioles: bracts nearly or quite as long as the corolla. — Bull. Soc. Bot. Belg. xxx. 294 (whence description is compiled). — Near Rio Jesus Maria Puntarenas, Costa Rica, *Pittier*, no. 502. Not seen by the writer.

++ ++ Leaflets oblong.

= Margin of legume bearing very short recurved hairs; valves pubescent and often strigillose.

10. **M. affinis**, Robinson. Pinnæ 1 pair; leaflets 8 to 12 pairs, acutish: peduncles shorter than the petioles. — Bot. Gaz. xvi. 341. — Grassy land near Mazatlan, *W. G. Wright*, nos. 1218, 1265; hillsides near Tequila, *Pringle*, no. 5453; Colima, *Palmer*, no. 131 (coll. of 1897); wet soil near Cuernavaca, Morelos, *Pringle*, no. 6662.

= = Valves of the legume glabrous; margins setose with straight spreading bristles: pinnæ 1 or more commonly 2 approximate pairs.

11. **M. pudica**, L. The well known sensitive plant of cultivation, very variable as to pubescence: occasional scattered spines as well as the infra-stipular usually present. — Spec. i. 518; Benth. Trans. Linn. Soc. xxx. 397, where extensive synonymy is given. — Common throughout tropical America from S. Mexico southward; Orizaba, *Bourgeau*, no. 2400; Vera Cruz, *Bourgeau*, no. 1759, *C. L. Smith*, no. 999, *Nelson*, nos. 159, 393; Costa Rica, *J. D. Smith*, no. 5767; Honduras, *J. D. Smith*, no. 5219, *Niederlein*; Panama, *Fendler*, no. 96, *Seemann*, no. 102. (Also extensively naturalized in the warmer countries of the Old World and said to be spontaneous in some parts of our Southern States.)

+ + Stems decidedly ligneous.

++ Spines infra-stipular or scattered: pinnæ 1 or 2 pairs: fruit (where known) rather narrow, not exceeding 8 mm. in breadth.

= Leaflets 13 to 25 mm. long.

a. Branchlets and peduncles scabrous-pubescent.

12. **M. tricephala**, Cham. & Schlecht. Spines straight: leaflets 10 to 15 pairs, ovate-oblong, 1–2-nerved, glabrous above, strigose beneath, 1.2 cm. long. — Linnæa, v. 591; Benth. Trans. Linn. Soc.

xxx. 394 (whence foregoing description). — Mexico near Actopan, *Schiede*, acc. to Benth. (Trop. Am.).

b. Branchlets and peduncles smooth or merely puberulent.

1. Leaflets ovate or broadly oblong.

13. **M. lactiflua**, Delile. Shrub: spines few, scattered, straight: leaflets 3 to 5 pairs, obliquely ovate or oblong, somewhat rigid, glaucescent beneath, pinnately veined, glabrous on both surfaces; margins slightly cartilaginous, incurved, ciliate with rigidulous stramineous setæ: flower 4-merous: legume unknown. — Delile acc. to Benth. Trans. Linn. Soc. xxx. 393, & in Mart. Fl. Bras. xv. pt. 2, 311. — Regarding the Mexican occurrence of this species Bentham (from whom the preceding description is compiled) says, "Delile's specimens were from the Botanical Garden of Montpellier, supposed to be of American, perhaps Brazilian origin. In the Berlin Herbarium there is a specimen from Mexico which agrees with the detailed description I had made (now inserted in the Flora Brasiliensis) except that the leaflets are under instead of over ½ in. long." While this species is known to me only from description I would refer to it Mr. Nelson's no. 1845, collected 9 km. above Dominguillo, Oaxaca, altitude 1375 to 1700 m.

2. Leaflets rather narrowly oblong.

14. **M. sicyocarpa.** Shrub, 1 to 2 m. high, sparingly armed with short scattered recurved spines: branches terete: petioles slender, glandless, 5 or 6 cm. in length, usually armed below the middle with a single short recurved spine: pinnæ a single pair, 1 dm. in length; leaflets 9 to 11 pairs, oblong, oblique at the base, subacute, mucronate, dull green and finely soft-pubescent upon both sides, slightly paler beneath, 20 to 25 mm. in length, a third as broad: peduncles axillary, often geminate, finely pubescent, unarmed: flowers 4-merous: legumes lance-oblong, 25 to 30 mm. long, 8 mm. broad, covered upon margin and valves with weak straight spreading stramineous setiform spines. — Collected by *E. W. Nelson* on roadside between San Sebastiana and the summit of the mountain known as the Bufo de Mascota, Jalisco, altitude 1550 m., 20 March, 1897, no. 4101. The bristling pods crowded in dense globular heads recall the fruit of the star-cucumber.

15. **M. cærulea**, Rose. Stems unarmed, nearly or quite glabrous, 6 to 9 dm. high, straight and terete: leaflets narrowly oblong, 12 mm. in length, acutish, mucronate, green on both sides, appressed setose-ciliolate, minutely appressed-puberulent or sparingly strigose varying to glabrous, reticulate-veiny: peduncles fascicled: flowers purplish,

4-merous, staminate and perfect: legume with glabrous valves; margin armed with very short incurved prickles. — Contrib. U. S. Nat. Herb. v. 141. — On foot hills and in mountain woods above Cuernavaca, *Pringle,* nos. 6200, 6385 (distrib. by clerical error as *cærulescens*); and between Guichocovi and Lagunas, Oaxaca, *Nelson*, no. 2746. A beautiful and very distinct species.

= = Leaflets 8 to 10 mm. long.

a. Branchlets and peduncles strigillose or covered with a sparing sub-appressed scabrous pubescence.

16. **M. Nelsonii.** Scabrous-puberulent shrub, 3 to 6 dm. high: branches woody, covered with a dull gray bark; branchlets warty-roughened: petioles short, scabrous-puberulent; pinnæ 1 pair; leaflets 5 to 11 pairs, broadly oblong, rounded at both ends, appressed-ciliate, of firm subcoriaceous texture, slightly lucid, 7 to 9 mm. long, 4 mm. broad, when young finely pubescent upon both sides but sometimes early glabrate, or perhaps glabrous at first, often (especially the lowest one) strigillose beneath: peduncles considerably exceeding the petioles, somewhat pubescent and strigillose: globose heads 10 mm. in diameter; bracts shorter than the buds, inconspicuous; flowers 4-merous, perfect and staminate: fruit light-colored, oblong, 2 cm. in length, 6 mm. in breadth, 3–4-jointed, hispid throughout with spreading curved bristles. — Collected in fruit by *Dr. Edward Palmer* near Acapulco, between October, 1894, and March. 1895, no. 88, and in flower by *E. W. Nelson*, between San Geronimo and La Venta at 665 m. altitude, 13 July, 1895, no. 2775 (in herb. U. S. Nat. Mus.). A species nearly related to the Lower Californian *M. Xanti*, but differing in its more sparing and scabrous pubescence, and much shorter bracts. Palmer's specimen is armed with straight scattered spines, while Nelson's is unarmed, yet their identity cannot be doubted.

b. Pubescence of branchlets and peduncles more copious, tawny-tomentose, spreading, softer in character.

17. **M. Xanti**, Gray. Leaflets 4 to 9 pairs, oblong, pubescent upon both sides, cinereous beneath, scabrous-ciliolate upon the margin, about 8 mm. long: bracts exceeding the buds and conspicuous in the young heads: legume 2–4-jointed, stipitate, 2 cm. long, covered with fine pubescence and short scattered setæ both upon valves and margins. — Proc. Am. Acad. v. 157; Benth. Trans. Linn. Soc. xxx. 396; Brandegee, Proc. Calif. Acad. Sci. ser. 2. iii. 133. — Lower Calif. near Cape St. Lucas, *Xantus,* no. 29; *Brandegee*, no. 183.

++ Spines numerous, small, recurved, somewhat 4-seriate: pinnæ 4 to 5 pairs: fruit 2 cm. broad.

18. **M. leptocarpa**, Rose. A straggling shrub with long lax glabrous branches: pinnæ 4 to 5 pairs, often alternate; leaflets 8 to 11 pairs, oblong, obtuse, minutely puberulent (under lens): legume 12 or 15 cm. long, 2 cm. broad; replum armed with a few short firm recurved prickles. — Contrib. U. S. Nat. Herb. i. 326. — Manzanillo, *Palmer*, no. 1341 (December, 1890). An anomalous species known only in fruit, so that even its generic affinities are subject to some doubt. Dr. Rose has found the remains of five stamens clinging about the base of the legumes. The fruit is of course extraordinarily large for *Eumimosa*, but seems to possess the distinctive characters of the genus.

Subg. 3. Habbasia, DC. (as extended by Benth.). Stamens twice as many as the lobes of the corolla. — DC. Mém. Lég. xii. 418 & Prodr. ii. 428; Benth. Trans. Linn. Soc. xxx. 389, 411.

* Flowers in cylindrical lax or dense elongated or rarely (in *M. adenantheroides*) subcapitate spikes. — *Leptostachyæ*, Benth. l. c. 389, 412.

+ Leaflets 1 to 5 rarely 7 pairs, elliptical, ovate, or obovate, not twice as long as broad.

++ Leaflets and younger parts tomentose or tomentulose.

= Leaflets 15 mm. or more in length.

19. **M. spirocarpa**, Rose. Showy tomentose shrub, sparingly armed with scattered spines: pinnæ 2 to 4 pairs; leaflets 1 to (less frequently) 3 pairs, broadly obovate: short-peduncled spikes numerous, rather slender, 7.5 cm. in length, purplish turning white: corolla 5-lobed: pods small, light-colored, tomentulose, soon coiled through 1 to 1½ revolutions. — Contrib. U. S. Nat. Herb. iii. 316, t. 11. — Sinaloa, Culiacan, *Palmer*, no. 1476, H., and later between Rosario and Colomas, *Rose*, no. 1606. Notwithstanding the exceptional form of the fruit there can be no doubt that Dr. Rose has correctly determined the affinities of the species.

20. **M. guatemalensis**, Benth. Fulvous-tomentose shrub armed with a few scattered straight spines: pinnæ 3 to 6 pairs; leaflets 3 to 6 pairs, elliptical: spikes 5 cm. long on peduncles half as long; flowers silky-villous: legume still unknown. — Bot. Sulph. 89, & in Hook. Lond. Jour. Bot. v. 89. *Inga? Guatemalensis*, Hook. & Arn. Bot. Beech. 419. — W. Mexico, Cerro de Pinal, *Seemann*, Tepic, *Barclay* (acc. to Hemsl.), *Lamb*, no. 583, near Colomas, *Rose*, no. 3200; Realejo, Nicaragua, *Sinclair*.

= = Leaflets 7 to 10 mm. in length.

21. **M. distachya**, Cav. Covered throughout with a fine close puberulence or tomentulose pubescence: spines stout, recurved, solitary on the internodes, directly beneath the leaves or removed from them or rarely absent: pinnæ about 3 pairs; leaflets 2 to 5 pairs, obovate, not crowded, finely and closely pubescent upon both surfaces: spikes geminate from the axils, pedunculate, rather short and dense. — Icon. iii. 48, t. 295; Benth. Trans. Linn. Soc. xxx. 417. — Mazatlan, Sinaloa, *Rose*, no. 1393; Cordillera of Oaxaca, *Galeotti*, no. 3240, acc. to Benth. (Also S. Am.). Dr. Rose's specimen shows the hitherto unknown legume to be oblong, 3.6 cm. in length, about 5-seeded, sharply tipped, puberulent and unarmed or armed on the margin with a few scattered short weak prickles.

++ ++ Leaflets and younger parts of stem glabrous or merely puberulent.

= Valves of fruit hispid with numerous tawny bristles.

22. **M. Brandegei.** A spreading shrub, 2 to 3 m. high: spines single or double, stout, recurved, borne mostly near the middle of the internode: pinnæ 3 to 4 pairs: leaflets 2 to 4 pairs, obovate, nearly concolorous, glabrous above, puberulent (under lens) beneath, 9 to 15 mm. long, rounded but slightly mucronate at the summit; rhachises sparingly pubescent: spikes single or fascicled by 2's or 3's, peduncles 3 or 4 cm. long: flowers white or nearly so: young fruit narrowly oblong, minutely pubescent and also bristly-setose. — *M. distachya?* Brandegee, Proc. Calif. Acad. Sci. ser. 2, iii. 133, not Cav. — San José del Cabo, Todos Santos, La Paz, Lower Calif., *Brandegee*, no. 184 (herb. Gray, herb. Brandegee).

= = Fruit glabrous, unarmed.

23. **M. laxiflora**, Benth. Shrub, glabrous or nearly so, with striate branches and stoutish recurved spines: pinnæ 3 or 4 pairs; leaflets 3 to 5 pairs, obovate, glabrous or early glabrate, 7 to 10 mm. long, about 3-nerved: spikes solitary or geminate, lax; flowers essentially glabrous, white: pods oblong, thin, glabrous, stramineous, unarmed, about 8-seeded. — Benth. in Hook. Lond. Jour. Bot. v. 93, & Trans. Linn. Soc. xxx. 418. ? *Acacia prosopoïdes*, DC. Prodr. ii. 460; A. DC. Calques des Dess. t. 210. — Gattunas, Sierra de la Union, near the southern boundary of New Mexico, *Schott;* mountains of N. W. Sonora, *Pringle*, 12 August, 1884; S. W. Chihuahua, *Palmer*, no. 41 (1885); near Guaymas, *Palmer*, no. 169 (coll. of 1887); Sonora Alta, *Th. Coulter*, no. 522, acc. to Hemsl.

Var. zygophylloides. Leaflets reduced to a single terminal pair on each secondary rhachis, 4 to 6 mm. long, slightly rounder, thicker, and more veiny than in typical form. — Collected in flower at Manzanillo, Colima, by *Prof. M. E. Jones*, 25 June, 1892, no. 193 (herb. U. S. Nat. Mus.). The peculiar arrangement of the leaflets here corresponds to that in *M. Rosei*, characterized below, but the leaflets themselves, even at full maturity, are not more than a third as large.

24. **M. Rosei.** Unarmed, glabrous: branches striate: stipules subulate; petiole and primary rhachis glandless, about 13 cm. long; pinnæ 4 pairs; secondary rhachises stipellate and geniculate near the base, 12 to 14 mm. long; leaflets, mostly a single pair, rhombic-obovate, obtuse, glabrous, deep green above, not lucid, somewhat paler green beneath, 15 to 22 mm. long, two thirds as broad: spikes axillary, solitary, (including short peduncle) 6 cm. long in fruit: legume (scarcely mature) linear-oblong, acuminate, flat, thin with firmer margin, about 8-jointed, 7 cm. long, 5 mm. broad; the segments sharply limited by straight transverse lines. — Collected in young fruit by *Dr. J. N. Rose*, at Balaños, Jalisco, 10 to 19 September, 1897, no. 2919.

= = = Fruit tomentulose but not setiferous.

25. **M. purpurascens.** Habit, thorns, &c., much as in *M. laxiflora*: pinnæ 4 to 5 pairs; leaflets about 4 pairs, 4 to 6 mm. long, puberulent (under lens) below; rhachises puberulent: spikes solitary or geminate, 4 cm. long including short peduncle; flowers subsessile, distinctly purplish: calyx finely pubescent: pods about 5-seeded, oblong, acute, 3.5 cm. long. — *M. laxiflora*, Brandegee, l. c., at least in part, not Benth. — Lower Calif., at La Paz, *Brandegee*, 4 February, 1890, no. 185, in flower, and at Purisima, 13 February, 1889, in fruit, secured by same collector. Some old fruit collected by *Xantus* in 1873, appears to be of the same species. Type in herb. Brandegee. Although near *M. laxiflora*, this plant cannot be satisfactorily referred to it.

+ + Leaflets 4 to 15 (rarely 20) pairs, linear to elliptic-oblong, mostly more than twice as long as broad: fruit not exceeding 1 cm. in breadth: shrubs, mostly armed.

++ Pods thin, sometimes setose but not tomentose; segments much broader than long.

26. **M. polyantha,** Benth. Shrub 1 to 2 m. high: spines stout, recurved, solitary beneath the axils: leaves not fully developed at time of flowering: pinnæ 2 to 3 pairs; leaflets 4 to 8 pairs, oblong, small, glabrous above, sparingly appressed-pubescent or glabrous beneath, about 5 mm. long: spikes numerous, 4 or more fascicled at each node of the

flowering branches; flowers glabrous: fruit oblong, 4 cm. long, 8 mm. broad, about 8-seeded, abruptly acuminate at each end, thin, lucid, hispid on margin and valves with short spreading setæ. — Benth. in Hook. Jour. Bot. iv. 410, & Trans. Linn. Soc. xxx. 417. — Acatlan, *Andrieux* (acc. to Benth.); Tomellin Cañon, Oaxaca, altitude 775 m. *Pringle*, no. 4635 (distrib. as *M. disticha*); Acaponeta, Tepic, *Rose*, no. 1475; also in W. Mexico, *Palmer*, 1891–1892, without number. The fruit of this species was unknown to Benth. The still sparing material available has the fruit most often hispid and that form of pod is accordingly assumed to be typical. A doubtful form with glabrous somewhat more numerous and relatively narrower leaflets has been collected without fruit in Oaxaca by *L. C. Smith*, no. 202, and *Nelson*, no. 2629.

Var. levior. Fruit nearly or quite free from hispidity: otherwise indistinguishable from the plant here regarded as typical. — Collected in W. Mexico, 1891–1892, by *Dr. Edward Palmer*, but without number or more precise data. Types in herb. Gray and herb. U. S. Nat. Mus.

++ ++ Pods tomentose, armed or unarmed; segments subequilateral or longer than broad.

= Stems not glandular.

a. Calyx subtruncate, very short, 0.8 mm. long, a quarter the length of the corolla: spikes long.

27. **M. Palmeri**, Rose. Large shrub, unarmed or with occasional infra-stipular spines: pinnæ 9 to 15 pairs; leaflets 7 to 10 pairs, elliptic-oblong, not crowded, glabrous above, puberulent beneath: spikes (including peduncles) 7 to 10 cm. long, numerous in showy terminal leafless panicles; flowers purplish, puberulent: young fruit linear-attenuate, tomentulose. — Contrib. U. S. Nat. Herb. i. 99. — Near Alamos, *Palmer*, no. 628; collected in flower in September.

28. **M. fasciculata**, Benth. Shrub with stout angulate branches and tawny or rusty-tomentose branchlets: spines short, broad-based, dark red, mostly infra-axillary, commonly grouped by 2's or 3's: leaves when well-developed 2 to 3 dm. in length; pinnæ 11 to 20 pairs; leaflets 8 to 15 pairs, oblong, villous-tomentose upon both sides: spikes crowded in a terminal raceme; flowers silky-villous: pods narrow, attenuate, ferrugineous-tomentose and hispid with numerous reddish brown rigidulous setæ. — Benth. in Hook. Lond. Jour. Bot. v. 88, & Trans. Linn. Soc. xxx. 414; Wats. Proc. Am. Acad. xxii. 409. *M. cinerea*, Herb. Pavon acc. to Benth. l. c. *Acacia fasciculata*, Kunth, Mim. 75, t. 23. — Originally collected near Guanajuato by *Humboldt & Bonpland;* later by *Karwinski* without exact locality; on hillsides near

Guadalajara, Jalisco, *Palmer*, no. 449 (coll. of 1886) in fruit, *Pringle*, nos. 2914, 4459, in flower; near Tamazulapam, Oaxaca, *Nelson*, no. 1962.

Var. **malacocarpa**. Fruit fulvous-tomentose but nearly or quite devoid of prickles. — Collected by *E. W. Nelson*, between Amolac, Puebla, and Sochi, Guerrero, altitude 1200 to 1260 m., 28 November, 1894, no. 2023, and by *J. N. Rose*, at Bolaños, Jalisco, September, 1897, no. 2917. Indistinguishable from the typical form except by its strikingly different fruit. The original specimens of *Acacia fusciculata* described by Kunth were not in fruit, so it is impossible to say which form was the original one. Under the circumstances it seems best to adopt as the typical form the one of which the fruit was first described (see Wats. l. c.).

b. Calyx more distinctly toothed, 1 to 1.5 mm. long, a third to half the length of the corolla: spikes shorter and thicker.

1. Spines mostly dark-colored, not greatly compressed.

29. **M. cœlocarpa**. Shrub, armed with small scattered straight spines; bark of branches gray: pinnæ 6 to 8 pairs; leaflets oblong, acutish, green on both sides, appressed-puberulent upon margin and lower surface, 3 mm. long, eccentrically 1-nerved, thin; stipules setaceous: spikes mostly geminate in the upper axils, moderately loose; peduncles slender, 14 to 18 mm. long: buds obovoid: flowers white with roseate tinge: corolla 4-parted: stamens 1 cm. in length: pods oblong-linear, acute at both ends, unarmed, tomentulose, 4 or 5 cm. long, 5 mm. broad; margins thickened; segments distinctly concavo-convex, the seed more or less prominent within the concavity. — Collected at Topolobampo, Sinaloa, Mexico, by *Dr. Edward Palmer*, 15 to 25 September, 1897, no. 187. Near the next, but distinguished by its peculiar fruit, longer peduncles, looser spikes and thinner leaflets. Types in herb. Gray and herb. U. S. Nat. Mus.

30. **M. Wrightii**, Gray. Shrub, armed with scattered spines: branchlets tomentulose, angulate; leaves much as in the last but thicker, varying from tomentose to subglabrous: peduncles shorter, 1 to 1.5 cm. long: spikes short and at first very dense; buds subglobose, tomentose: pods rusty-tomentose, unarmed; margins thick; segments not distinctly concavo-convex. — Pl. Wright. ii. 52; Benth. Trans. Linn. Soc. xxx. 417. — Mountains of Arizona, *Palmer*, *Pringle*, *Toumey*, nos. 37, 38; Sonora, *Wright*, no. 1041 (type); Chihuahua, *Pringle*, no. 359, *Hartman*, no. 732. A greener and usually less tomentose plant than the next species.

2. Spines light-colored, conspicuously compressed and very broad at the base.

31. **M. dysocarpa**, Benth. Shrub with stems angled: pinnæ 6 to 12 pairs; rhachis elongated, slightly armed with small scattered spines; leaflets 7 to 16 pairs, densely silky-villous almost tomentose, somewhat cinereous, oblong, 4 to 6 (to 8) mm. in length, acutish: spikes at first dense, at length laxer, 2.5 to 7.5 cm. long exclusive of the much shorter peduncle, subpaniculately aggregated at the summit of the stem: calyx and pods tomentose, the former 2 mm. or more in length, turbinate below; the latter 2.5 to 5 cm. long, about 6-seeded, more or less constricted between the seeds, sharply acuminate, unarmed or provided with a few short curved spines on one edge. — Benth. in Gray, Pl. Wright. i. 62, & Trans. Linn. Soc. xxx. 414, t. 66; Gray, Pl. Wright. ii. 51; Coult. Contrib. U. S. Nat. Herb. ii. 97. — Rocky hills, W. Texas, *Wright*, no. 163; New Mexico, *Thurber*, no. 1104, *Wright*, no. 1040; *Miss Mulford*, nos. 387, 696; Arizona, *Rothrock*, no. 511, *Rusby*, no. 113a, *Lemmon*, no. 2690; State of Durango, Mexico, *Palmer*, no. 418 (coll. of 1896).

= = Stem covered with minute sessile or stipitate glands.

32. **M. adenantheroides**, Benth. Stem puberulent, glandular-punctate: spines recurved: pinnæ about 9 pairs; leaflets about 9 pairs, obliquely oval, obtuse, 3-nerved, pubescent, pale beneath: spikes fascicled by 3's; flowers pubescent. — Benth. in Hook. Lond. Jour. Bot. v. 88; & Trans. Linn. Soc. xxx. 416. *Acacia adenantheroides*, Mart. & Gal. Bull. Acad. Brux. x. pt. 2, 310. — On calcareous and gneissic mountains of Sola and Yolotepeque, Cordillera of Oaxaca, at 2153 to 2307 m., *Galeotti*, no. 3208. Description compiled. Near this species must stand two differing yet doubtfully distinct plants collected in the mountains of Oaxaca by *Nelson*, and represented by his nos. 2078 and 1479. Both differ from the above description in having only 3 to 5 pairs of pinnæ, but without fuller knowledge of Bentham's species can neither be identified with it nor positively excluded from it.

+ + + Leaflets 15 to 40 pairs, oblong: fruit not 1 cm. in breadth: unarmed tree.

33. **M. puberula**, Benth. Pinnæ 5 to 10 pairs; leaflets 15 to 40 pairs, crowded, oblong, rigid, obtuse, 4 to 5 mm. long: spikes axillary, 4 to 5 cm. long: fruit stipitate, flat, pubescent. — Benth. in Hook. Lond. Jour. Bot. v. 88, & Trans. Linn. Soc. xxx. 413. — Zimapan, *Th. Coulter*, and "New Spain" Herb. Pavon, acc. to Benth. Description compiled.

+ + + + Leaflets 15 to 40 pairs: fruit over 1.5 cm. broad: armed shrub, not glandular.

34. **M. platycarpa**, Benth. Thorns scattered, recurved: pinnæ 6 to 10 pairs; leaflets 15 to 25 pairs, linear, 2 to 3 mm. long: spikes slender, loosely flowered: fruit stiped, flat, glabrous, nearly 4 cm. in length. — Trans. Linn. Soc. xxx. 417. — Guatemala, *Skinner* (acc. to Benth.). Description compiled.

+ + + + + Leaflets 22 to 40 pairs, linear-oblong: stem arborescent; branches armed, glandular-pubescent.

35. **M. Cabrera**, Karst. Small tree armed with scattered straight spines: pinnæ 5 to 8 pairs; leaflets 18 to 35 pairs, 5 mm. long, concolorous, pubescent upon both sides: flowers somewhat verticillate in long flexuous interrupted spikes: legume flat, pubescent. — Fl. Colomb. ii. 63, t. 132; Benth. Trans. Linn. Soc. xxx. 416. ? *M. tenuiflora*, Poir. Suppl. i. 82, not Benth. ? *Acacia tenuiflora*, Willd. Spec. iv. 1088. — ? San Salvador, *Wendland* (acc. to Benth. & Hemsl.); Valley of Comayagua, Honduras, *Niederlein*. Northern S. America. If Bentham is right in stating that this species is the same as *Acacia tenuiflora*, Willd., there seems no reason why Poiret's *Mimosa tenuiflora* should not be taken up for it upon grounds of priority, but on a comparison of an authentic specimen of *M. Cabrera*, with Willdenow's original description there appear to be several striking differences rendering real identity impossible. *M. Cabrera* is called by the Spanish Americans "carbon" or "carbonal" and its wood is, acc. to Niederlein, used to make charcoal.

* * Flowers in globose, ovoid or (in *M. monancistra*) subcylindric heads.

+ Shrubs or trees with hard wood, rarely (in *M. Lemmoni* and *M. Grahami*) only undershrubs: branchlets mostly armed with scattered or infra-stipular never seriate spines: pubescence never strigose: corolla not striate.

++ Pubescence not rufous: pods setose or spinose upon the valves.

= Pod oblong or moniliform, not over 1 cm. broad.

36. **M. monancistra**, Benth. Low shrub with flexuous grayish often striate branchlets: internodes armed by a single short recurved subaxillary spine (which is frequently some distance beneath the leaf insertion): pinnæ 2 to 3 pairs; leaflets mostly 4 pairs, oblong or elliptical, obtuse, 3 to 6 mm. long, appressed-pubescent: heads ovoid or short-cylindric; flowers silky-tomentulose: pods 3 to 5 cm. long, acuminate, 3–7-jointed hispid with stramineous setæ or weak spines. — Pl. Hartw. 12, & Trans. Linn. Soc. xxx. 425: Wats. Proc. Am. Acad. xvii. 350. — W. Texas, on the Rio Pecos, *Havard*, no. 66; Mexico, Tamaulipas, *Berlan-*

dier, nos. 831, 2251, 3145; Coahuila, *Gregg*, *Palmer*, no. 290 (coll. of 1880), *Pringle*, no. 217; Guanajuato, *Dugès;* Aguas Calientes, *Hartweg*, no. 70 (type); Jalisco, *Rose*, nos. 3572, 3665; Michoacan, *Pringle*, no. 3733; Oaxaca, *L. C. Smith*, no. 18.

37. **M. Emoryana**, Benth. Branchlets tomentulose; spines single but borne usually at the side of (not often beneath) the axils: leaves small, appressed-tomentulose and cinereous; rhachis scarcely over 6 mm. in length; pinnæ about 2 pairs, crowded, 8 mm. long; heads globose: young fruit as in the last. — Trans. Linn. Soc. xxx. 426. — Gravelly hills near the Cibolo of the Rio Grande, *Bigelow*, 28 July, 1852, no. 312, which was the type number, although it was cited in the original description by clerical or typographical error as no. 302; also foothills of the Chisos Mts., W. Texas, *Havard*, no. 18.

38. **M. minutifolia**, Rob. & Greenm. Shrub armed with straight or slightly recurved infra-stipular subaxillary or scattered spines: pinnæ 10 to 20 pairs; leaflets numerous, not over 1 mm. in length, pubescent upon the edge and lower surface: valves tough, oblong, not constricted between the seeds, apparently falling away entire, at first somewhat canescent-tomentulose as well as covered with tawny or rufescent setæ. — Am. Jour. Sci. ser. 3, l. 150. — Rocky hills, Rio Blanco, Jalisco, *Pringle*, no. 5142, and near Colotlan, *Rose*, no. 2673; the specimens of both collections are in fruit.

= = Pod lanceolate, 2 cm. broad.

39. **M. eurycarpa.** Small tree, 4 to 6 m. high, glabrous or puberulent, sparingly armed with scattered spines or unarmed: branches reddish brown; branchlets green, angulate: stipules setaceous: leaflets narrowly oblong, 6 to 8 mm. in length, 2 mm. in breadth, 1-nerved, rounded at the apex, deep green upon both surfaces: heads numerous, small, fasciculate, racemose at the ends of the branchlets; bracts short scarcely showing in the young heads: calyx fully half the length of the glabrous white 5-lobed corolla: stamens 10: pods large, lance-oblong, acuminate, 6 to 7 cm. long, 2 cm. broad; stipe long and slender; valves echinate, separating entire from the replum, which is weakly armed on one side. — Collected by *E. W. Nelson* between Guichocovi and Lagunas, Oaxaca, at 175 to 275 m. altitude, 27 June, 1895, no. 2741; also between La Venta and Niltepec, at 60 m. altitude, 14 July, 1895, no. 2798. Mr. Nelson's no. 955 without fruit is probably the same.

++ ++ Pubescence not rufous: pod surrounded by a lacerate wing; valves neither setose nor spinose.

40. **M. lacerata**, Rose. Stout shrub, 15 to 25 dm. high, armed with pairs of dark brown laterally compressed very broad based infra-stipular spines: pinnæ 5 to 9 pairs; leaflets 8 to 17 pairs, canescent-puberulent: legumes brown, oblong, obtuse at the apex and base, 4 to 5 cm. long, 1.5 cm. broad, including the lacerate wings. — Contrib. U. S. Nat. Herb. v. 141. — Vicinity of Piaxtla, Puebla, at 1200 m. altitude, *Nelson*, no. 2008; also on limestone hills between Tehuacan, Puebla, at 1850 m. altitude, *Pringle*, no. 6247 (distributed by clerical error as *M. lacerans*).

++ ++ ++ Pubescence rufous, dense.

41. **M. mollis**, Benth. Pinnæ 4 to 5 pairs; leaflets 6 to 10 pairs, oblong, villous upon both sides, 8 to 12 mm. long: heads fascicled at the nodes; flowers villous. — Benth. in Hook. Jour. Bot. iv. 408, & Trans. Linn. Soc. xxx. 429. — Mexico, *Andrieux*, no. 400. Species not seen by the writer; the description compiled.

42. **M. Galeottii**, Benth. Tall shrub or small tree, 3.5 to 4.5 m. high, with stoutish flexuous branches: branchlets densely covered with short rufous thickish hairs: spines infra-stipular and geminate or solitary: leaves subsessile, 6 to 10 cm. long; pinnæ 20 to 25 pairs, 10 to 18 mm. long; leaflets about 16 pairs, 2 to 3 mm. long, nearly glabrous except upon the shortly ciliate margins: peduncles fascicled in the axils, 14 to 17 mm. long, copiously and retrorsely pubescent with thick tawny hairs: flowers yellowish turning roseate: pod (acc. to Benth.) broadly linear, glandular-puberulent, setose-prickly upon the sutures, almost naked on the valves. — Benth. in Hook. Lond. Jour. Bot. v. 92, & Trans. Linn. Soc. xxx. 429. *Acacia hirta*, Mart. & Gal. Bull. Acad. Brux. x. pt. 2, 318. — Forests of Yolotepeque, western Cordillera of Oaxaca, altitude 2460 m., *Galeotti*, no. 3165. It cannot be doubted that this species is also represented by Mr. Pringle's no. 6384 collected on mountain sides above Cuernavaca at 2150 m. altitude. This number was unfortunately distributed as *M. lacerans*, Rose, n. sp.?

++ ++ ++ ++ Pubescence not rufous: pod (still unknown in *M. tenuiflora*) often armed upon the margin, but neither surrounded by a wing nor setose upon the valves.

= Pinnæ a single pair; leaflets 1 pair on each secondary rhachis, obovate, or suborbicular, 2 to 4 mm. in length.

43. **M. zygophylla**, Benth. Small much-branched shrub with single intra-nodal spines: petioles short, thickish, somewhat flattened;

small leaflets obovate or suborbicular, 2 to 4 mm. in diameter: pods unarmed or rarely bearing a few marginal spines. — Benth. in Gray, Pl. Wright. i. 61, & Trans. Linn. Soc. xxx. 425. — Common on limestone hills of Northern Mexico; near Monterey, *Gregg*, no. 182; Saltillo, *Wislizenus*, no. 300, *Gregg;* Parras, *Palmer*, no. 296 (coll. of 1880); Carneros Pass, *Pringle*, nos. 2851, 3703.

= = Pinnæ 1 pair; leaflets 2 to 4 pairs, obovate or suborbicular, 2 cm. in length.

44. **M. leucænoides**, Benth. Tall shrub or small tree, 3 to 4.5 m. in height, unarmed: petioles rather short (1 cm. in length): leaflets at first puberulent, later glabrate, lucid, subcoriaceous, veiny: heads axillary, racemose and subcorymbose at the ends of the branches: legume 5 to 6.5 cm. long, 4 to 8 mm. broad, unarmed. — Benth. in Hook. Lond. Jour. Bot. v. 89, & Trans. Linn. Soc. xxx. 421. — Zimapan, *Th. Coulter*, and Mexico without locality, *Karwinski*, acc. to Hemsl. *Pringle's* no. 3750 collected on limestone ledges at Las Palmas, San Luis Potosi, doubtless represents this species.

= = = Pinnæ 1 to ∞ pairs; leaflets 2 to ∞ pairs, oblong to elliptic, mostly small.

a. Branchlets, petioles, and rhachises glabrous even under lens.

1. Spines infra-stipular, geminate.

45. **M. tenuiflora**, Benth. Stipules setaceous: pinnæ 1 to 3 pairs, obliquely oblong: peduncles somewhat longer than the leaves, the upper ones racemose. — Benth. in Hook. Lond. Jour. Bot. v. 92, & Trans. Linn. Soc. xxx. 429. — Zimapan, Mexico, *Th. Coulter;* Mexico without further locality, *Karwinski*, acc. to Benth. Species not seen by the writer; the description compiled.

2. Spines (with rare exceptions) single, borne at the side of the axil and 30° to 120° removed from it.

46. **M. borealis**, Gray. Shrub, 1.5 to 2.5 m. high: leaves small; pinnæ mostly a single pair; leaflets 3 to 5 pairs, oval, 2 to 4 mm. long, two thirds as broad, thickish, glaucescent: peduncles very slender, 12 to 18 mm. long: legumes 2.5 cm. or more long, unarmed or more often armed on one or both edges; segments about 4, rounded at the sides. — Pl. Fendl. 39, & Pl. Wright, i. 61 (excl. var.), ii. 51; Benth. Trans. Linn. Soc. xxx. 426, t. 66. *M. fragrans*, Gray, Pl. Wright, ii. 51, not Pl. Lindh. — W. Texas, *Wright*, *Hayes*, no. 220, *Havard*, no. 68; New Mexico, *Fendler*, no. 181, *Wright*, no. 1038, northward to Cimarron Valley, Indian Terr., *Carleton*, acc. to Holzinger. Perhaps only a variety of the next.

47. **M. fragrans**, Gray. Fragrant shrub, 6 to 12 dm. or more

high, in technical characters too close to the last preceding species, but with much more developed foliage: pinnæ 1 to 3 pairs, oblong, 2 to 3 cm. in length; leaflets in about 6 somewhat remote pairs, oblong, 4 to 6 mm. in length: legumes curved, about 5 cm. long, slightly or not at all armed; segments 5 to 7. — Pl. Lindh. pt. 2, 182, as to plant of Lindh.; Benth. Trans. Linn. Soc. xxx. 426. — Thickets on rocky soil, S. and W. Texas, *Lindheimer*, nos. 606, 607, *Wright*, no. 1037, *Reverchon*, no. 717 * (of Curtiss' distrib.), *Havard*, no. 63, *Heller*, no. 1594.

b. Branchlets, petioles, or at least rhachises puberulent to tomentose.

1. Pods thin and soft in texture, wholly unarmed, 4 to 5 mm. broad, velvety tomentose.

48. **M. calcicola.** Shrub 6 to 9 dm. high: branches gray, flexuous, armed with solitary recurved subaxillary spines: pinnæ 2 to 3 pairs; leaflets elliptic-oblong, 2 to 3 pairs, subdistant, at least not crowded, pale green, puberulent, concolorous, 3 to 5 mm. long: peduncles axillary, solitary, puberulent, 8 mm. long; flowers pubescent, white or nearly so: pods 3 to 4 cm. in length, about 6-seeded, slightly constricted between the seeds, light colored, permanently canescent-tomentose. — Collected by *C. G. Pringle*, on calcareous plains of Tehuacan, State of Puebla, at 1525 m. altitude, 29 July, 1897, no. 6765 (distributed as *M. depauperata*?)

2. Pods coriaceous, more or less armed upon one or both edges.

○ Pinnæ 1 to 2 or rarely 3 pairs; leaflets 2 to 6 pairs.

49. **M. depauperata**, Benth. Low rigidly branched shrub, becoming 1 m. high, finely canescent-puberulent: spines single, subaxillary: leaves very small; pinnæ a single pair; leaflets 2 or 3 pairs, ovate, not 2 mm. in length; common petiole 6 mm. long, somewhat flattened: peduncles 5 mm. in length: flowers canescent-pubescent: young pods stipitate, 6-jointed, canescent-pubescent upon the valves, aculeate upon one edge, distinctly constricted between the seeds. — Benth. Pl. Hartw. 13, in Hook. Jour. Bot. iv. 410, & Trans. Linn. Soc. xxx. 425. *Acacia canescens*, Mart. & Gal. Bull. Acad. Brux. x. pt. 2, 312. — Plains of Actopan, Mexico, *Graham* (fragmentary specimen in herb. Gray); Mexico without locality, *Karwinski* acc. to Benth.; also from hills near San Juan del Rio, Queretaro, *Pringle*, no. 6352, showing young fruit as above described. A specimen collected on a gravelly mesa near Presidio, Texas, *Havard*, no. 75, has mature glabrate constricted pods (7 mm. in breadth) and the reduced foliage of this species, but somewhat longer peduncles and smoother flowers. Near to and

perhaps confluent with this species are the plants referred by Dr. Gray to his *M. borealis* var.? *Texana*, Pl. Wright, i. 61 (*Wright* no. 159, also no. 10, coll. of 1851, and *Gregg*, no. 51). They differ from *M. borealis* in their puberulent rhachises and subaxillary spines, but are to a certain extent intermediate between *M. depauperata* on the one hand and *M. acanthocarpa* and *M. biuncifera* on the other. Without better and more copious material their affinities and proper status cannot be more exactly determined.

50. **M. Pringlei**, Wats. Branching shrub armed with mostly geminate infra-stipular spines: pinnæ 1 to 2 pairs; leaflets 2 to 4 pairs, elliptical or oval, pale green: flowers canescent-puberulent; bracts inconspicuous: pods glabrous, 2 cm. long, acute, slightly armed on one edge or unarmed. — Proc. Am. Acad. xxi. 452. — Near Big Cañon of the Rio Grande, W. Texas, *Havard*, no. 12, and on rocky hills near town of Chihuahua, *Pringle*, in fruit, October, no. 545, and in flower, August, no. 724.

○ ○ Pinnæ (at least on well developed leaves) 3 to ∞ pairs; leaflets mostly numerous.

+ Pods 7 to 10 mm. broad, mostly obtuse or obtusish.

52. **M. Grahami**, Gray. Stem nearly glabrous: primary rhachises (nearly 1 dm. in length) sparingly pubescent; pinnæ about 10 pairs; leaflets 15 to 20 pairs narrowly oblong, of firm texture, paler and prominently veined beneath, entirely glabrous upon both surfaces, usually devoid even of ciliation: pods glabrous at maturity. — Pl. Wright. ii. 52. — Mountain valleys of Northern Sonora, near the Arizonan boundary, *Wright*, no. 1042.

53. **M. Lemmoni**, Gray. Apparently an undershrub, covered with soft and canescent pubescence or tomentum: pinnæ about 6 pairs; primary rhachis 6 to 10 cm. long; secondary rhachises often 4 cm. in length; leaflets elliptic-oblong, pubescent-tomentose, 5 to 7 mm. in length: heads numerous, globular, borne on filiform geminate peduncles which are sometimes grouped in showy compound racemes: pods even at maturity canescent-tomentose. — Proc. Am. Acad. xix. 76. — Huachuca Mountains, Arizona, *Lemmon*, nos. 2692, 2693, *Pringle*, no. 7, *Toumey*, no. 39. Too near the next, from which it differs chiefly in its smaller spines, less woody stems, and larger less crowded leaflets.

54. **M. acanthocarpa**, Benth. Stems and branches decidedly ligneous: spines mostly numerous, slender or stout, usually paired and infra-stipular, with or without a third one beneath the leaf-insertion; scattered spines sometimes present also: leaves (except on young and

vigorous shoots) seldom exceeding 4 cm. in length; pinnæ 4 to 10 pairs; leaflets oblong, crowded, ciliate, pubescent, 4 to 5 mm. long: pods oblong, straight or nearly so, armed on one or both edges, canescent-tomentose, at least when young, obtusish but mucronate-tipped. — Benth. in Hook. Jour. Bot. iv. 409, & Trans. Linn. Soc. xxx. 428; Wats. Proc. Am. Acad. xvii. 350. *M. biuncifera*, Torr. Bot. Mex. Bound. 61, in part, acc. to Wats. Bibl. Index, 243. — Mexico without locality, *Graham;* San Luis Potosi, *Schaffner*, no. 624; Jalisco, *Rose*, no. 2572; Durango, *Rose*, no. 3491, and (acc. to Benth.) nos. 301 and 308 of Mex. Bound. Survey. Bourgeau's no. 486, referred to this species, should be placed in *M. biuncifera*.

+ + Pods 4 to 6 mm. broad, mostly acute or acutish.

55. **M. prolifica**, Wats. Shrub armed with long slender straight geminate spreading infra-stipular spines: leaf-rhachis 4 to 6 cm. in length, pubescent, armed with hooked spines; pinnæ about 8 pairs; leaflets 8 to 18 pairs, oblong, acutish, ciliate or quite glabrous, 3 mm. in length: pods copious, falcate, narrowed to a point at both ends, armed upon the ventral (convex) suture. — Proc. Am. Acad. xxi. 452. — Rocky hills near Chihuahua, *Pringle*, no. 208 in flower, no. 372 in fruit. A species too near the variable *M. biuncifera*, and distinguished from it chiefly by its larger leaves and long slender straight spines.

56. **M. biuncifera**, Benth. Straggling shrub or small tree: spines usually broad, laterally compressed, paired and infra-stipular, or single and infra-axillary, or rarely occupying both positions: primary leaf-rhachis 6 to 31 mm. long; pinnæ 3 to 9 pairs; leaflets 5 to 13 pairs, oblong, 2 to 3 mm. in length: flowers canescent-puberulent or -tomentulose: pods about 6-seeded, usually more or less constricted between the seeds, puberulent or rarely tomentulose, seldom over 5 mm. broad. — Pl. Hartw. 12, in Hook. Jour. Bot. iv. 409, & Trans. Linn. Soc. xxx. 428; Gray, Pl. Wright. i. 61, ii. 51. — Rocky ground on foothills and mountains, W. Texas, *Wright*, to Arizona, *Rothrock*, *Pringle*, *Palmer*, *Toumey:* Mexico, Chihuahua, *Pringle*, no. 367: San Luis Potosi, *Parry & Palmer*, nos. 215, 216; Durango, *Palmer*, no. 328 (with small fruit), 594; Jalisco, *Pringle*, no. 6199; State of Mexico, *Andrieux*, no. 399, *Bourgeau*, no. 486? *Pringle*, no. 6308; Oaxaca, *Nelson*, no. 1571. Variation striking but mostly permiscuous and not yet subject to clear definition.

Var. **flexuosa**. More slender: branches flexuous or almost geniculate: leaflets minute, 1 to 1.5 mm. long: flowers canescent-tomentulose as in the typical form. — *M. flexuosa*, Benth. in Gray, Pl. Wright. i. 62,

& Trans. Linn. Soc. xxx. 428. — W. Texas, *Wright*, no. 161; New Mexico, *Wright*, no. 1365.

Var. **Lindheimeri.** Inconspicuously puberulent but with flowers nearly or quite glabrous: mature leaflets 3 to 4 mm. long. — *M. Lindheimeri*, Gray, Pl. Lindh. pt. 2, 181; Benth. l. c. 429. — W. Texas, *Lindheimer.* Mr. Pringle's no. 5152 from Michoacan is essentially the same.

* * * Herbs, undershrubs, or soft-woody often scandent shrubs, frequently setiferous or strigose.

+ Corolla multistriate.

57. **M. somnians,** H. & B. Undershrub, glabrous to densely glandular-villous, armed with straight scattered usually infrequent spines: pinnæ 2 to ∞ pairs; leaflets 12 to 28 pairs, linear-oblong, 2 to 4 mm. long: pods long-stiped, linear or narrowly oblong, acute, 8–11-seeded, glabrous to glandular-pilose. — H. & B. in Willd. spec. iv. 1036; Kunth, Mim. 20, t. 7; Benth. Trans. Linn. Soc. xxx. 434. *M. palpitans*, H. & B. l. c. *M. somniculosa,* HBK. Nov. Gen. & Spec. vi. 257. *M. acutiflora* & *M. podocarpa,* Benth. in Hook. Jour. Bot. iv. 397. — Widely distributed in Trop. America, and reaching Central America and S. Mexico: Oaxaca, *Nelson*, no. 2723 (smoothish form), no. 881 (glandular form); Guatemala, *Hayes*, and no. 6104 of J. D. Smith's set; Panama, *Seemann*, no. 105.

58. **M. trijuga,** Benth. Unarmed undershrub? pinnæ 3 to 4 pairs: leaflets 30 to 50 pairs: pod glabrous. — Benth. in Hook. Jour. Bot. iv. 398, & Trans. Linn. Soc. xxx. 434. — Tropical America, extending to Panama, *Hayes,* acc. to Benth. from whom the description is compiled.

+ + Corolla not striate: stems strongly angled, and angles armed with short recurved spines.

++ Canescent-tomentose to glabrous: leaflets obovate or elliptic: spines of the upper part of the stem and peduncles not especially numerous or conspicuous.

59. **M. malacophylla,** Gray. Tomentose: stems 2 to 5 m. long, climbing over shrubs: primary leaf-rhachis 1 to 1.5 dm. long; pinnæ 3 to 6 pairs; leaflets 4 to 6 pairs; distinctly although obtusely pointed, mucronate: pods more or less constricted between the seeds, 5 to 7.5 cm. long, 8 to 10 mm. broad, 5–8-jointed, smooth; valves disarticulating between the seeds. — Pl. Lindh. pt. 2, 182, & Pl. Wright. i. 52; Benth. Trans. Linn. Soc. xxx. 423. — S. W. Texas, in the valley of the Rio Grande, *Wright,* no. 164; Mexico, Nuevo Leon, *Gregg*, no. 207, *Pringle,* no. 1905; Coahuila, *Palmer*, no. 299 (coll. of 1880); Chihuahua, *Bigelow,* no. 319.

Var. glabrata, Benth. Stems, &c., merely puberulent: leaflets somewhat larger, green and glabrous, mucronate as in the typical form. — Benth, l. c. *M. malacophylla*, var. *glabra*, Gray in Torr. Bot. Mex. Bound. 61 (name only). — On the lower Rio Grande, *Schott*, *Miss Croft*, and earlier at San Fernando, Tamaulipas, *Berlandier*, nos. 815, 2235.

60. **M. polyancistra**, Benth. Climbing (?) glabrous shrub: spines small, numerous, recurved: pinnæ 3 to 7 pairs; leaflets 6 to 8 pairs, oblique, obovate-oblong, mucronate. — Trans. Linn. Soc. xxx. 422. — "New Spain," *Pavon*. Description compiled.

++ ++ Tawny-tomentose: leaflets oblong: spines on the upper part of the stem and peduncles not conspicuous.

61. **M. Ervendbergii**, Gray. Pinnæ about 5 pairs; petiole and primary rhachis 1 dm. long, armed (as in related species) by numerous short recurved spines; leaflets about 12 pairs, 7 to 10 mm. long,. 3 mm. broad, acutish at the apex, oblique at the base, discolorous, sordid-tomentose beneath: heads numerous, paniculate; peduncles 2 cm. long, unarmed: fruit unknown. — Proc. Am. Acad. v. 178, in part. *M. costaricensis*, Benth. Trans. Linn. Soc. xxx. 423, ex char. — Wartenberg near Tantoyuca, Huasteca, Mexico, *Ervendberg*, no. 2 (herb. Gray) in part. This species was founded upon mixed material and it is now clear that the specimen to which Dr. Gray referred when he mentioned the young leaves is *M. invisa*, H. & B. Bentham seems never to have understood Dr. Gray's species, referring to it *Schrankia elata*, Mart. & Gal. which from its armed peduncles cannot be the plant here retained as *M. Ervendbergii*, nor from its arborescent habit is likely to have been the other component of Dr. Gray's type. Furthermore Bentham also described *M. costaricensis*, which in all characters mentioned corresponds accurately to *M. Ervendbergii*, as here interpreted. If, as is surmised, *M. costaricensis* proves identical, the range of the species may be extended to Costa Rica, where coll. by *Oersted*, and Guatemala, *Salvin*, acc. to Hemsl.

++ ++ ++ Loosely pubescent: leaflets linear to linear-oblong: upper part of the stem and often peduncles covered with very numerous reflexed stramineous spines.

62. **M. invisa**, Mart. Petioles rather long, copiously armed; pinnæ 4 to 8 pairs; leaflets 12 to 25 pairs, 3 to 4 mm. long, 1 mm. broad: heads in simple elongated terminal raceme; peduncles very short, villous and often armed; heads rose-purple. — Herb. Fl. Bras. 121; Benth. Trans. Linn. Soc. xxx. 436. *M. diplotricha*, Wright in Sauv. Pl. Cub. 34, acc. to Benth. *M. Ervendbergii*, Gray, l. c. in part. *Schrankia*

brachycarpa, Benth. in Hook Jour. Bot. ii. 130, iv. 415. — Tropical America: S. Mexico, Huasteca, *Ervendberg;* Guatemala, nos. 211 & 6105 of J. D. Smith's sets.

A noteworthy form, coll. at Mazatlan, Sinaloa, *Lamb*, No. 329 (distrib. as *M. Ervendbergii*) has straighter spines and longer less pubescent unarmed peduncles.

+ + + Corolla not striate: pubescence not strigose: spines scattered, not seriate: pods short, 1–3-jointed, narrow, not over 5 mm. in breadth.

++ Densely villous with long spreading yellowish hairs.

63. **M. camporum**, Benth. Prostrate, nearly herbaceous, scarcely armed: stipules ovate, striate: pinnæ about 6 pairs; leaflets numerous, narrowly oblong: heads large, many-flowered, oval, including the long stamens 2.5 cm. in diameter; bracts long and conspicuous in the young heads, imbricated, ciliate, tawny-villous: pods 6 to 12 mm. long, 4 mm. broad. — Benth. in Hook. Jour. Bot. ii. 130, iv. 403, *M. flaviseta*, Benth. in Hook. Lond. Jour. Bot. v. 90. *M. æschynomenes*, Benth. Bot. Sulph. 89. — Acaponeta, Tepic, *Rose*, nos. 3116, 3295; Realejo, Nicaragua, *Hinds*, *Sinclair*, acc. to Hemsl. (Trop. Am.)

++ ++ Hispid with a few scattered setose spines, and sparingly pubescent.

64. **M. pusilla**, Benth. Prostrate annual: pinnæ 1 to 9 pairs, leaflets 6 to 12 pairs, oblong, 4 mm. long, heads small, few-flowered, 6 mm. in diameter; peduncles 1 cm. or less in length: pods 2–3-jointed, setulose on margin or valves, 3 or 4 mm. in breadth. — Bot. Sulph. 90. — Acapulco, *Palmer*, no. 9 (coll. of 1894–1895); Realejo, *Sinclair*, *Hinds*, acc. to Benth. & Hemsl. Although I have seen no authentic specimens of this species, I cannot doubt that it is represented by Dr. Palmer's specimen.

+ + + + Corolla not striate: pubescence usually strigose: pods 1-∞-seeded, 8 to 14 mm. broad.

++ Prostrate, herbaceous or nearly so: leaf-rhachis unarmed: pods 2–4-seeded.

65. **M. strigillosa**, Torr & Gray. Often rooting at the joints, scarcely or not at all armed: heads large, oval, usually long-peduncled: pods 2.5 cm. in length, oblique at the summit, acutish, setose throughout. — Fl. i. 399; Chapm. Fl. 115. — Pine barrens and hummock lands of Florida, westward to W. Texas: adjacent Mexico, *Berlandier*, *Gregg*, *Palmer*.

++ ++ Ascending or erect, suffruticose: leaf-rhachis armed with opposite acicular spines between the pinnæ; stipels also spinescent: pods short 1–3-seeded, obovate with broad oblique summit.

66. **M. dormiens**, H. & B. Whole habit and foliage of the following more abundant species, but softer appressed-villous rather than

strigose pubescence, and strikingly different fruit. — H. & B. in Willd. Spec. iv. 1035; Benth. Trans. Linn. Soc. xxx. 435. *M. humilis*, H. & B. l. c. 1037. *M. intermedia*, Kunth, Mim. 16, t. 6. — Near Tapachula, Chiapas, *Nelson*, no. 3851; Central America, Herb. Pavon, acc. to Hemsl. (Trop. Am.)

+ + + Ascending or erect, suffruticose: leaf-rhachis usually armed by pairs of spines between the pinnæ; pods oblong, elongated, 4 to 9 cm. in length.

67. **M. asperata**, L. Strigose-hirsute: branches thickish, sub-herbaceous, pithy, armed with scattered or opposite, laterally compressed broad-based brown or light gray spines: pinnæ 4 to 9 pairs; leaflets 12 to 40 pairs, linear-oblong, acutish, crowded, puberulent, ciliolate: peduncles rather stout, 2 to 5 cm. long; pods oblong, rounded and mucronate at the apex, covered throughout by short stiffish upcurved tawny hairs: valves dividing into 15 to 20 short broad segments. — Syst. Nat. ed. 10, 1312; Benth. l. c. 437 (where extensive synonymy is cited); *M. pigra*, L. l. c. *M. polyacantha, hispida*, & *canescens*, Willd. Spec. iv. 1034–1038. *M. pellita*, H. & B. in Willd. l. c. 1037; Kunth, Mim. 27, t. 9. — Widely spread in the tropics of both hemispheres. Mexico, between San Luis Potosi and Tampico, *Palmer*, no. 1037 (coll. of 1878–1879); Jalisco, *W. G. Wright*, no. 1335, *Rose*, nos. 1422, 1564, *Nelson*, no. 4136; Colima, *Palmer*, no. 1377; Vera Cruz, *Bourgeau*, no. 2209, *Nelson*, no. 526, *C. L. Smith*, no. 998; borders of Oaxaca, *Nelson*, nos. 2333, 2856; Guatemala, nos. 1735 and 3294 of J. D. Smith's sets; Panama, *Fendler*, no. 98, *Seemann*, no. 527.

Var. Berlandieri. Less pubescent: stems merely strigillose: leaves shorter than in the typical form; pinnæ 4 to 6 pairs; primary rhachis only 3 to 5 cm. long, mostly unarmed: pods sparingly hispid with short more or less strigose hairs, segments of the valves 8 to 15. — *M. Berlandieri*, Gray in Torr. Bot. Mex. Bound. 61; Benth. l. c. 423. — Valley of the Rio Grande, near Matamoras, *Berlandier*, no. 3146; Micos, San Luis Potosi, *Pringle*, no. 3798. Careful search fails to show any significant or constant difference between this and *M. asperata*, which can be regarded as a specific distinction. Mueller's no. 90 from Vera Cruz, Hartmann's no. 519 and Lamb's no. 511 from Sinaloa, show clear transitions to the typical form.

II. REVISION OF THE NORTH AMERICAN SPECIES OF NEPTUNIA.

Neptunia, Lour. (Dedicated to *Neptune* from the preference for aquatic habitat.) — Unarmed aquatic or terrestrial perennials, herbaceous or suffrutescent. Leaves bipinnate, more or less sensitive; leaflets small, oblong, sometimes glandular at the base. Flowers small, aggregated in dense globose, ovoid, or short-cylindric heads; the lowest flowers frequently sterile and with each filament broadened into a conspicuous linear-lanceolate yellow lamina. Fruit strongly compressed, several-seeded, more or less stipitate. — Fl. Cochinch. 653; Benth. in Hook. Jour. Bot. iv. 354–356, & Trans. Linn. Soc. xxx. 383–385; Coult. Contrib. U. S. Nat. Herb. ii. 95, *Desmanthus* § *Neptunia*, DC. Prodr. ii. 444. *Hemidesmas*, Raf. Sylv. Tell. 119. — About 9 species of the warmer parts of both Old and New World.

N. OLERACEA, Lour. l. c. 654, a tropical floating species with enlarged spongy stems (often 1 cm. thick) has been thought to occur in Texas, see Griseb. Fl. W. Ind. 217, but no specimens from the U. S. have been available. (Mex., *Rovirosa*, W. Ind., S. Am., Tropics of Old World.)

* Heads large, subcylindric, about 50-flowered: lower flowers more often uniform with the rest: bracts lanceolate, inconspicuous.

N. lutea, BENTH. Pubescent with rather fine weak spreading hairs: stems prostrate, branched, 9 to 15 dm. long: leaves with 3 to 5 pairs of pinnæ; leaflets 8 to 16 pairs, rounded at the ends, pubescent and ciliolate, 3 to 7 mm. long; stipules small, ovate-lanceolate, chestnut-colored: peduncles axillary, 5 to 7.5 cm. in length, 12 to 16 mm. in breadth, commonly pubescent, 3–9-seeded; stipe often 8 mm. long. — Benth. in Hook. Jour. Bot. iv. 356, & Trans. Linn. Soc. xxx. 384. *Mimosa virgata*, Batr. Trav. 421, acc. to Wats. Bibl. Index, 244. *Acacia lutea*, Leavenw. Am. Jour. Sci. vii. 61, acc. to Torr. & Gray, Fl. i. 403, but originally described as glabrous and with shorter peduncles. *Darlingtonia virgata*, Raf. New Fl. pt. 1, 43, acc. to Wats. l. c. — Moist and clayey soil, S. Missouri, *Bush*, to Texas, "Alabama, *Leavenworth*," and Florida, *Leavenworth*, but apparently rare southeastward. Var. TENUIS. Closely similar but with stems and peduncles nearly or quite glabrous. — *N. tenuis*, Benth. ll. cc. — Texas, *Drummond*, no. 150 of 3rd collection, *Berlandier*, no. 1602 near Austin and no. 1851, also *Lindheimer*, no. 48, and *Hall*, at Hemstead, no. 178.

* * Heads considerably smaller, ovoid, about 20-flowered; the lowest flowers often with yellow petaloid filaments: bracts ovate, acuminate.

+– Bracts and calyx-lobes ciliolate.

N. pubescens, Benth. Habitally similar to the preceding, finely pubescent or at length only glandular-roughened: pinnæ only 2 or 3 pairs but leaflets more numerous (15 to 35 pairs), ciliolate upon the margin but not otherwise pubescent; stipules larger than in the preceding species, ovate, acuminate, yellowish-brown or greenish: legumes rather short and broad (about 10 mm. in breadth), 3–8-seeded, more or less pubescent; the stipe only a line or two in length. — Benth. in Hook. Jour. Bot. iv. 356, & Trans. Linn. Soc. xxx. 384 (excl. pl. of Florida and perhaps of W. Ind.); Coult. l. c. *N. lutea*, Torr. Bot. Mex. Bound. 60, in part, acc. to Wats. Bibl. Index, 244. — S. and W. Texas, from Corpus Christi Bay, *Palmer*, to Eagle Pass, *Havard*, and perhaps farther westward, *Wright*, (Mex., W. Ind.). This of all our plants appears to correspond most closely to specimens from Peru whence the species was originally described.

N. Lindheimeri. Diffusely branched from a lignescent base, conspicuously and persistently pubescent: pinnæ 3 to 5 pairs; leaflets 15 to 30 pairs, strongly ciliated on the margin and also pubescent upon the lower surface, especially near the apex; stipules, bracts, and even the calyx-lobes conspicuously ciliated: fruiting peduncles 2.5 to 6.5 cm. long: pods regularly oblong, cuneate at the base, 2.5 to 3.8 cm. long, 8 mm. broad, more or less pubescent even in age, 3–10-seeded; stipe about 4 mm. long. — *N. lutea*, Heller, Contrib. Herb. Frankl. & Marsh. Coll. i. 45, not Benth. — Prairies of Texas, about Houston, *Lindheimer*, June, 1843, Texas without locality, *Wright*, and near Corpus Christi, *Heller*, no. 1822.

+– +– Bracts and calyx-lobes not ciliolate.

N. floridana, Small. Very slender and apparently very sensitive: stems branched, 6 dm. or more long, prostrate, glabrous: pinnæ 3 to 4 pairs; leaflets numerous (15 to more often) 20 to 40 pairs, ciliolate but not otherwise pubescent: peduncles long, at anthesis often hooked at the apex, in fruit 7.5 to 10 cm. in length: bracts and calyx-teeth quite devoid of ciliation: pods about 3.2 cm. long, 6 mm. broad, sparingly pubescent when young, soon glabrate, 7–9 seeded; stipe 2 to 6 mm. in length. — Bull. Torr. Club, xxv. 138. *N. pubescens*, Benth. Trans. Linn. Soc. xxx. 384, in part (as to pl. Rugel). *N. lutea*, Chapm. Fl. ed. 1 & 2, 117, at least in part, not Benth. *Acacia lutea*, Torr. & Gray, Fl. i. 403, as to pl. from Florida. *Desmanthus luteus*, Chapm.

Fl. ed. 3, 128, at least in part, not Benth. — Florida, St. Marks, *Rugel*, 1843; Apalachicola, *Chapman;* Miami, *Garber*, 1877; rocky pine woods between everglades and Biscayne Bay, *Curtiss*, no. 726; hummock land in clayey soil, near Eustis, *Nash*, no. 686; also collected in Mississippi at Ocean Springs, *Pollard*, no. 1104 (distrib. as *Acuan Illinoensis*), and in Louisiana, *Hale.* (St. Domingo, *Eggers*, no. 2552; Cuba, *Wright;* S. Am.?) Chiefly distinguished by its elongated peduncles and unciliated calyx.

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ON THE SOURCES OF LUMINOSITY IN THE ELECTRIC ARC.

BY HENRY CREW AND OLIN H. BASQUIN.

INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

ON THE SOURCES OF LUMINOSITY IN THE ELECTRIC ARC.*

By Henry Crew and Olin H. Basquin.

Presented by Charles R. Cross, March 9, 1898.

When one considers any actual source of luminous energy, many possible causes of luminosity suggest themselves. In the case of an ordinary tallow candle, we have a considerable development of heat at a temperature high enough to melt platinum, while at the same time hydrocarbons are vaporized, decomposed, and again united with elements of the atmosphere, to form the well known gaseous products of combustion. Is the light of the candle flame immediately due to the high temperature or to the chemical action which is going on? Evidently these chemical processes do not take place except at high temperatures. This fact, however, only makes high temperature a necessary, not a sufficient, condition of luminosity. Kayser and Runge have shown that a large part of the spectrum of the carbon arc is due to the union of carbon and nitrogen,— perhaps to form CN. Runge and Paschen find that an atmosphere of oxygen is almost a *sine qua non* for obtaining the compound line spectrum of S and Se.

In the Plücker tube, in the electric arc, and in the electric spark, we have, beside chemical affinity and high temperature, still another possible cause of luminosity, viz. the electric and magnetic field.

Why does the oscillatory discharge † give the blue spectrum of argon, and the deadbeat discharge the red spectrum? Is the temperature so different in these two cases as to account for the different spectra, or does the rapidity with which the electric potentials vary determine to some extent the *kind* of atomic shock produced? That the atomic motions are affected by a magnetic field is a part of the recent brilliant discovery of Zeeman.‡

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* The following investigation has been made possible through financial aid extended by the Trustees of the Rumford Fund.

† Trowbridge and Richards, Amer. Jour. Sci., Vol. III. pp. 15–20 (1897).

‡ Work of Graham at Berlin shows that the rate of variation of potential in the Geissler tube keeps pace with the variation of luminosity, — as R. W. Wood observed to be the case with temperature.

Of the three processes, thermal, chemical, and electrical, at work in the ordinary electric arc, to which is immediately due the light of the arc? Or is the light partly due to one process and partly due to another? And, if so, what is the character of the radiation due to high temperature alone, what that due to chemical action, and what that immediately due to the electric current?

Some general questions of this character suggested the following experiments. But the one definite question which these experiments were intended to answer may perhaps be more clearly stated in terms of the nomenclature which E. Wiedemann * has employed in his suggestive work on the Mechanics of Luminosity. Using his nomenclature, all sources of luminosity (*Licht-entwicklung*) are either *normal* or *luminescent.* The luminosity of a body is *normal* when it is produced by high temperature *alone,* — i. e. the luminosity of a body is normal when it satisfies the condition of Kirchhoff's Law. Bodies which become luminous through other causes than that of high temperature are said to be *luminescent.* The process of producing light without a corresponding high temperature is called "luminescence." Wiedemann distinguishes six different kinds of luminescence. One or two will serve to illustrate the process. Fluorescence, in which luminosity is brought about by mere illumination, is called *photo-luminescence.* The light produced by breaking lump sugar, or by rapidly unwinding bicycle tape, is an instance of frictional-, or *tribo-luminescence.* The radiation which comes from a slightly heated piece of fluorspar illustrates *thermo-luminescence.*

These and many other instances of luminescence are well known.† But it may be fairly doubted whether "normal luminosity" has ever been experimentally realized.

Dr. Paschen,‡ of Hannover, has recently shown, in the most beautiful and satisfactory manner, that a gas so slightly heated as to preclude the supposition of any chemical change going on within it will emit an invisible spectrum. This spectrum he has determined by means of the bolometer, and has shown it to be a characteristic spectrum. Whatever the inferences which may be drawn from Paschen's experiment, no one, so far as we are aware, has shown that high temperature alone will produce a visible spectrum which is linear or characteristic. The following experiments are an attempt to answer this question, *Is it possible by heat alone to obtain the characteristic visible spectrum of a gas?*

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* For an excellent résumé of Wiedemann's ideas and terminology, see Winkelmann's article on *Phosphorescenz* in his Handbuch der Physik.

† It is here not to be forgotten that even a most excellent nomenclature, such as Wiedemann's, does not of itself add anything to our understanding of the actual processes named. It is, however, a great aid to clear thinking and clear writing.

‡ Paschen, Wied. Ann., Bd. L. pp. 409–413 (1893).

We wish to distinctly avow at the outset that our answer is not so definitive as is to be wished. Having, however, perfected a practical experimental method for maintaining a metallic vapor at an exceedingly high temperature and isolated from electric influence, — more exactly an electric or magnetic field, — a report upon this part of the work, together with several incidental results, is now submitted.

The method employed to separate the electrical, chemical, and thermal effects — or, more properly, to isolate the thermal effects — is as follows. The process involves three steps: —

(1) The use of an electric arc between chemically pure metallic poles.

(2) The use of this arc in gas which is chemically inert with respect to the electrodes.

(3) The examination of this arc during a very minute interval of time when the current is off the arc, and only after an interval in which the self-induction effects have had time to die down and disappear.

Metallic electrodes are used, since they are freer from impurities and much less complicated, from a chemical standpoint, than carbon.

This arc is then worked in an air-tight metallic box, and this box is flooded with a gas which is chemically inactive towards the electrodes. We have used principally iron poles in hydrogen. This hydrogen is prepared electrolytically by a current varying from 10 to 20 amperes; the small box containing the arc is thus swept out continually by a current of fresh and dry hydrogen amounting to 100 cc. per minute. On the way to the arc this hydrogen is passed successively through two drying tubes of strong sulphuric acid and phosphoric anhydride.

It is not to be forgotten, however, that, while iron and hydrogen are inactive with respect to each other at ordinary temperatures, the laws of high-temperature chemistry and low-temperature chemistry are radically different, so that there is always the possibility of some unknown chemical action at the high temperature of the electric arc. The arc was viewed through a glass window in one wall of the air-tight hood.

To exclude the electric current for an instant and examine the hot metallic vapor immediately afterwards, the following device was used.

An alternating dynamo of 100 volts was employed to feed the arc. But in series with the armature, and on the same shaft with the armature, were placed two interrupters, which cut out either all the positive or all the negative parts of the alternating current.

In either case, the current is broken at the instant represented by the current-curve crossing the axis of *X*. The intervals *A′B′*, *A″B″*, etc. in Figure 1, are the intervals during which the current is heating the arc; while the intervening intervals *B′A″*, *B″A‴*, etc., are the intervals during which the visual or photographic examination of the arc is made.

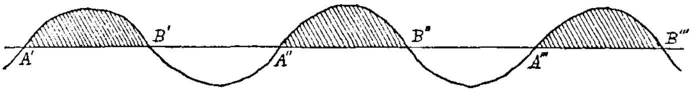

FIGURE 1.

The interrupting disks, placed in circuit one on each side of the arc, are made of rather heavy brass rings, 30 cm. in diameter, and insulated from the shaft on which they rotate. Into the faces of these brass rings are set two slate sectors, each 45° in length, as represented in Figure 2.

A pair of large brush holders is centred on the same shaft with the interrupters. Each holder carries two brushes, which bear on the interrupter at points 90° apart. Since the dynamo is an eight-pole machine, it is evident that the current will be "on" half the time and "off" half the time, both sides of the circuit being opened and closed alternately at the end of each 45° of rotation.

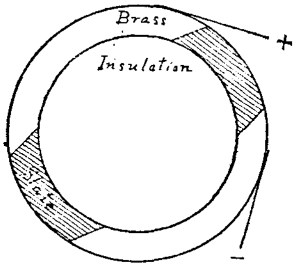

FIGURE 2.

The brush holders are, of course, adjustable so that they may be set at a position of minimum sparking. But one defect of this method of interruption is that the brushes must have a finite thickness, and hence can never cross the boundary between brass and slate without *some* sparking. Not only so, but as the phase of the current changes with load to a slight extent, the angular adjustment of the brushes can never remain perfect. To reduce these changes of phase to a minimum the terminals of the dynamo were kept on a closed circuit all the while, the poles of the machine being shunted through a bank of incandescent lamps. So that the arrangement of the complete circuit was as in Figure 3.

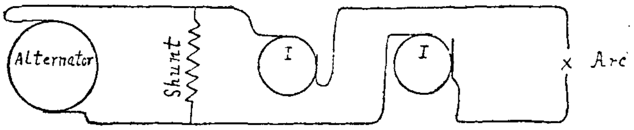

FIGURE 3.

Still a third source of sparking lies in the slight inaccuracy of dimensions in the interrupter rings as they come from the mechanician. While the spark which thus remains is larger than we should like, it has not at all injured the sharp line of contact between the brass and the slate portions of the interrupter; and its only effect on the arc, so far as we are able to observe, is slightly to delay the break of the current, by furnishing, at the point of interruption, a bridge of metallic vapor.

So far as the method of experiment is concerned, it only remains to state how the intervals during which the current was off were employed to observe the arc. For this purpose a steel disk 71 cm. in diameter was placed on the end of the same shaft which carried the armature and the interrupters. Near the periphery of this disk were cut four openings, as indicated in Figure 4.

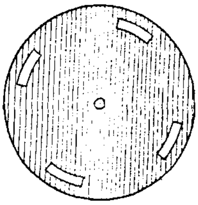

FIGURE 4.

These openings were provided with shutters, so that their angular width could be varied from 0° to 26°. Behind this disk (and at the same distance from the shaft as the centre of one of these openings) was placed the arc. The line of vision was parallel to the axis of the shaft. The steel disk was so adjusted, in azimuth, on the shaft that the light of the arc was excluded from the eye until the brush was 9½° on the slate sector. In like manner, the light was cut off from the eye of the observer 9½° before either brush had passed off the slate sector of the interrupter. The effective diameter of this steel disk was 59 cm. The disk was driven by a gas engine at 1,700 revolutions per minute, corresponding to a rim speed of over 50 meters per second.

Under these circumstances, no light was admitted to the eye until $\frac{1}{1000}$ of a second after the current had been cut off. And the line of vision was again interrupted $\frac{1}{1000}$ of a second before the arc was again made. In later experiments, the aperture was stopped down to $\frac{1}{1000}$ second in time; but the maximum time for which the arc was visible was $\frac{3}{1000}$ of a second.

At this point the question naturally arises as to whether the self-induction of the circuit can prolong the purely electrical effects, whatever they may be, through an interval of time as great as $\frac{3}{1000}$ of a second.

The form of the circuit is practically that of two parallel copper wires, each 180 cm. long and separated by a distance of 30 cm. If the current be not oscillatory [?] we may fairly assume that its time constant will lie somewhere between that of a circle of wire (having the same diameter as the wire actually used and enclosing the same area as the circuit actually used) and a 180 cm. section of two parallel wires 30 cm. apart and open at *both* ends.

Computing the time-constants for these two cases, we have* for the parallel wires,

$$L = 2\,\mu \log_\epsilon \frac{b^2}{a_1 a_2} + \tfrac{1}{2}\,(\mu_1 + \mu_2)\,;$$

$$\text{where} \left\{ \begin{array}{ll} L & = \text{self-induction of unit length.} \\ \mu & = \text{permeability of medium between wires.} \\ \mu_1 & = \text{permeability of one wire.} \\ \mu_2 & = \text{permeability of other wire.} \\ a_1 & = \text{radius of one wire.} \\ a_2 & = \text{radius of other wire.} \\ b & = \text{shortest distance between the axes of the wires.} \end{array} \right.$$

Here

$$\mu = \mu_1 = \mu_2 = 1,\ a_1 = a_2 = 0.1 \text{ cm., and } b = 30 \text{ cm.}$$

Hence,

$$L = 4 \log_\epsilon 300 + 1 = (4 \times 2.477 \times 2.30) + 1 = 23.$$

$$\text{Inductance of circuit 180 cm. long} = 23 \times 180 = 4140. \quad \text{C. G. S.}$$

$$\text{Resistance of 360 cm. of this wire} = 0.02 \text{ ohms approx.} = 2 \times 10^7 \text{ C. G. S.}$$

$$\therefore \text{Time-constant} = \frac{4140}{20000000} < \frac{1}{4000} \text{ sec.}$$

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* Gray, Absolute Measurements, Vol. II. Pt. I. p. 293.

If we consider the arc itself as having appreciable resistance, this time-constant is still smaller. If, on the other hand, we consider the actual circuit as equivalent to a circular one *of equal area*, the radius of this circular circuit will be 45 cm.

Its self-induction * will be

$$L = 4\ \pi\ a \left(\log \frac{a}{R} - 2\right),$$

where a is the radius of the circuit, 45 cm., and R is the "geometric mean distance" of the cross section of the wire from itself, defined by the following equation:

$$\log R = \log r - \tfrac{1}{4},$$

where $r =$ radius of cross section of wire.

Here $r = 0.1$ cm. Hence $R = 0.7788\ r = 0.0778$.

Hence

$$\begin{aligned} L &= 12 \times 45\ [\log 45 - \log 0.07788 - 2] \\ &= 12 \times 45 \times 2.3\ [1.653 - \bar{2}.891 - 2] = 12 \times 45 \times 4.35 = 2340. \end{aligned}$$

$$\therefore \quad \frac{L}{R} = \frac{2340}{2 \times 10^7} = \frac{1}{10000} \text{ sec., approx.}$$

In each of these cases it is to be borne in mind that the initial current, the decay of which we are studying, is but a minute fraction of the strength of the alternating current operating the arc.

The conclusion of the whole matter is, that there is no evidence, either from an examination of the arc or from electrical theory, that the current in this short isolated strip persists for a length of time comparable to one thousandth of a second.

In fact, the instant the brushes of the interrupters have passed on to the slate sectors, the whole circuit consists simply of two short pieces of thick copper wire with one pair of terminals nearly in contact, the other widely separated by a piece of slate carefully selected with reference to its high insulating power.

Further evidence will be furnished, by experiments to be described later, for thinking that the phenomena which appear when the current is off are quite independent of the self-induction of the circuit.

It need scarce be added, that in place of the eye of the observer, in front of the steel disk, may be substituted the spectrograph or the photographic camera. In this case, both arc and spectrograph are placed on a large table with a long hole cut into the top of it so as to clear the occulting screen, the arc on one side the screen, the camera on the other. Rubber corks, placed in the legs of this table, free it from serious vibration even in the neighborhood of high speed shafting.

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* Gray, Absolute Measurements, Vol. II. Pt. I. p. 308, Eq. (119′).

The spectrograph employed was made by Bartel of Göttingen. The collimator and objective had each an aperture of 1½ inches. The dispersion piece was a 2″ Rowland grating, 14,438 lines to the inch.

For the identification of the hydrogen lines which always made their appearance when an atmosphere of hydrogen was employed, this same instrument was used visually, a spectrum tube of hydrogen furnishing the comparison spectrum. Ordinarily, for the visual examination of the arc, a small direct-vision instrument was employed. For the examination of the fluorescent light, mentioned at the end of this paper, a Browning single prism instrument was tried with wide slit; also the direct-vision instrument; but the source was entirely too faint to produce a visible spectrum. The conclusions there stated, viz. that the spectrum of this fluorescent light is not characteristic, rest merely upon the fact that this light presents to the eye the same appearance for all the metals tried, viz. a luminosity resembling fluorescent light in general; and further, upon the *probability that, if this spectrum were concentrated in lines*, some of them might be visible in the spectroscopes employed.

For the purpose of determining the manner in which the rise and fall of the arc occurs when the circuit is made and broken, respectively, it is only necessary to move the eye either to the one side or the other so as to catch the light of the arc a little earlier or a little later than the instant of break.

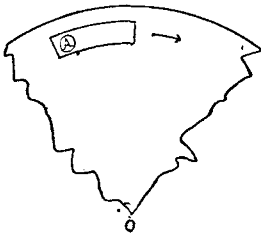

Figure 5.

Let *A* represent the arc as seen through an opening in the disk by an eye looking in a direction parallel to the shaft of the dynamo. Then by moving the head to the right one will see the arc in a later phase; since the line of vision above and parallel to the shaft will not be intercepted until a later instant. Hence, by moving the arc and head together slowly

FIGURE 8. Reduced one half.

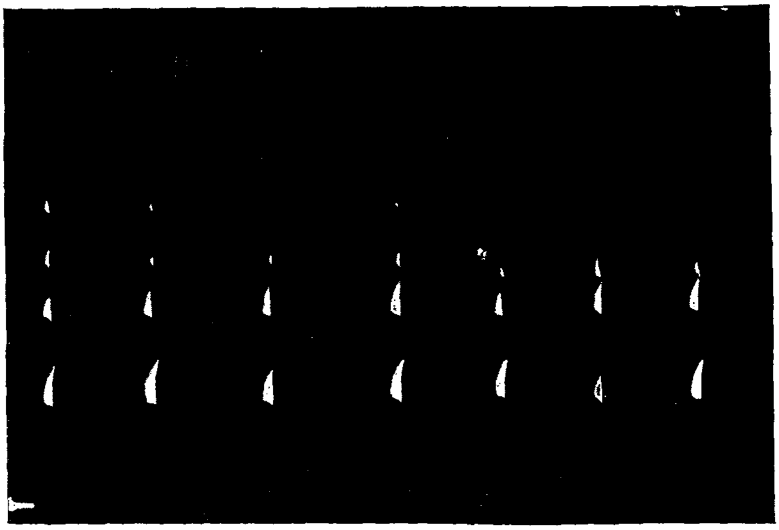

FIGURE 9. Reduced one half.

from a position just over the shaft to one on the right. one sees the rise of the current. In like manner, motion of the arc and head from a position just over the axis to one on the left will give the observer a chance to see the decay of the current.

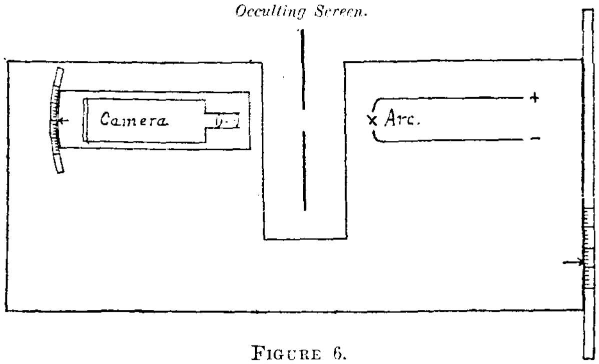

FIGURE 6.

For the purpose of photographing the arc in various stages of its rise and decay, we rigidly connected the arc and camera to a sliding table top; for each 5 mm. displacement of this table top the phase at which the arc is first seen or last seen is changed by $\frac{1}{10000}$ second. On this table the camera was so arranged as to rotate about a vertical axis passing through the optical centre of the lens. In this manner were photographed, on one plate, several series showing the arc in successive phases, differing by one or two ten-thousandths of a second.

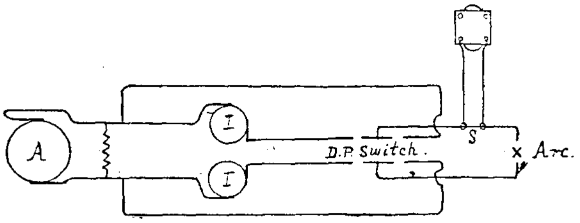

FIGURE 7.

I. THE INTERMITTENT ARC.

A double pole switch convenient to the observer enabled one to operate the arc either with the ordinary alternate current or by the alternate current which had passed through the interrupters. This latter we shall call, for convenience, the "intermittent" current. A voltage of approximately 70 was ordinarily used.

To the naked eye the appearance of these two arcs, the alternate and the intermittent, is the same except in size. But they present the following striking difference to an observer on the side of the occulting disk next the arc. Through the openings in the occulting disk, a lens projects an image of the arc upon a white screen on the side of the disk *away* from the arc. This screen is visible through the disk all the while. The alternating arc is visible upon the occulting disk and upon the screen at all times; but the intermittent arc is seen only on the occulting disk. The image appears to hang in mid-air, and although the white screen is seen with perfect distinctness the intermittent arc which is projected upon it bears little or no resemblance to that projected upon the occulting disk. The light which reaches the screen (that is, the light which penetrates the occulting disk) is that which has persisted after the current has been cut off. Such an occulting disk in connection with the interrupters, then, forms a most convenient means of separating radiations according to their length of life after the exciting current has been cut off.

II. The Persistent Luminosity of the Arc.

In the case of the iron arc, we have measured the duration of the luminosity after the current has been cut off and find that with a voltage ranging from 70 to 80 and a current varying from 10 to 20 amperes the life of the white luminous cloud that floats above the junction of the electrodes covers a period of from two to five thousandths of a second after the disappearance of the current.

By the use of the sliding table top we have photographed the rise and decay of the arc.

In Figure 8 are reproduced three series of seven photographs each. All of the series are taken under the same conditions. Each series, beginning at the left and going to the right, depicts the decay of the current. The first of the series represents the arc as it appeared $\frac{2}{10000}$ of a second *before* the current was interrupted. The last photograph, the one at the extreme right, represents the arc as it appeared $\frac{4}{10000}$ of a second *after* the current was interrupted. All the photographs were taken at equal intervals of $\frac{1}{10000}$ of a second. It is evident, therefore, that the third photograph was taken just as the brush of the interrupter passed on to the slate sector. It will be observed that the arc proper (which is represented by the bright triangular area in the first three photographs of each series) persists for about $\frac{1}{10000}$ second after the brush has passed on to the slate sector. But what remains longest of all is the detached white cloud which persists from eight to ten times the whole interval covered by one of these series of photographs. Each of the twenty-one photographs is a composite of about 200 single exposures, the whole 200 exposures occupying just two seconds.

In Figure 9 are reproduced seven series of four photographs, each series representing the *rise* or growth of the arc. Each series is arranged in a vertical column. The first photograph of the series, the one at the top, was taken $\frac{1}{10000}$ second after the circuit was closed, the next three are made at immediately succeeding intervals of $\frac{1}{5000}$ second. These are also composites of about 200 exposures, the whole set of 200 occupying but two seconds. It will here be seen that the luminous cloud which was so slow in disappearing is also tardy in making its reappearance.

In the third and seventh series no arc appears even after $\frac{1}{10000}$ second. A bouncing of the brush might explain this for a single exposure. But it is not so easily explained in a composite of 200 exposures.

In Figure 10 are reproduced six typical photographs of the detached cloud as it appears at the middle of the interval during which the current is off the arc. The bright point to the right is the red-hot iron electrode. The exposure is two seconds, aperture $\frac{1}{5}$ the focal length — "Carbutt A" plates — unit magnification. These six photographs are all taken in the same phase. It will be observed that no trace of the arc remains, but that the luminous cloud is as bright as red-hot, perhaps molten iron.

Whether or not this after-luminosity is a phenomenon corresponding to the "flame" which accompanies the carbon arc remains to be decided.

III. Effect of Self-Induction.

In order to discover whether self-induction had anything to do with the persistence of this after-luminosity, the primary of a 25-light transformer was put in series with the arc, the circuit being arranged as indicated in Figure 7, so that the switch S could throw in or cut out the transformer without interrupting the arc. No effect was certainly observable either by the eye or on the photographs, although the time-constant of the circuit must have been enormously increased.

So far as the evidence thus far presented is concerned, this persisting luminosity appears to be what Wiedemann would call chemi-luminescence, or thermo-luminescence, and not electro-luminescence.

IV. INTERMITTENT IRON ARC IN OXYGEN AND HYDROGEN.

In an atmosphere of oxygen, this persisting luminosity is very much increased ; while, when the hood of the arc is filled with hydrogen, the luminosity is very much decreased. In hydrogen, the light is also very red and yields the H_α and B_β lines (C and F of Fraunhofer) as already observed by Liveing and Dewar.*

After the arc has been working in oxygen for a few minutes the whole interior of the hood is lined with a light brown deposit, which is evidently iron oxide.

In hydrogen, on the contrary, the iron electrodes in the parts that become hot present a bright metallic surface, which shows the reducing effect of the hydrogen on the iron *oxide ;* but there is no evidence of any chemical action between the iron and the hydrogen.

So far as the brilliant luminosity of the iron arc *in oxygen* is concerned, it is evident that it might be due *either* to the oxidation of the iron *or* to the increased heat produced by this oxidation.

In the case of hydrogen, we should say that chemi-luminescence were ruled out were it not for the fact that in the hydrogen flame, which burns as it escapes from the chamber surrounding the arc, there is always a small white core, a flame in color not unlike that of ordinary illuminating gas or acetylene.

Since the hood was thoroughly cleansed from all forms of oil and grease, and since the bearings were run dry in clean asbestos packing, the only source of carbon would appear to be that which we know to be present as an impurity in the iron electrodes.

That this carbon impurity *is* the true source of the white flame is made highly probable by the fact that "chemically pure" zinc and magnesium poles gives no trace of it, the carbon in these being very much less than in the impure iron employed.

V. INTERMITTENT ARC OF PURE ZINC AND MAGNESIUM IN HYDROGEN.

To realize the conditions indicated in this caption may be considered the chief object of this experiment. For with a large current of fresh, dry, and pure hydrogen sweeping out the hood of the arc, we may feel fairly certain that oxidation is ruled out, except at the very start. Any of the original air in the hood still remaining, its oxygen would be very quickly used up after the arc was once started. Indeed, we always find a slight whitish deposit of oxide on the electrodes of Zn and Mg when the arc is started too early.

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* Liveing and Dewar, Proc. Roy. Soc., Vol. XXXV. p. 74 ; also Vol. XXX. p. 152.

And with pure zinc and magnesium poles we may feel fairly certain that no ordinary or well known chemical action is going on. Observations were taken only after the stream of hydrogen had been running through the hood for half an hour. After passing two tubes of phosphoric anhydride, it would seem wellnigh impossible that any moisture should remain in the hydrogen. Figure 11 shows the hooded arc in position.

Under these conditions, neither the arc nor the luminous cloud above the arc is to be seen. Though once in a long while a bit of yellow cloud flashes out for an instant. We have not been able satisfactorily to account for this.

The only light that remains, aside from that emitted by the red-hot electrode, is a sort of blue haze, — a blue glow, that fills the whole hood, and is there all the time. This light appears to be exactly the same for all three metals, iron, zinc, and magnesium. It is too diffused and faint to be easily examined in the spectroscope. Is this possibly a phosphorescence of hydrogen, or of the finely abraded particles of metal?

In reply then, to the main question, viz. can the characteristic spectra of the metals be produced by heat alone, we can only say that on heating metallic vapors to the temperature of the electric arc we are unable to discover any characteristic spectrum after an interval of one thousandth of a second.

The form of electrode used by us is, however, very favorable to the rapid cooling of the metallic vapor; and we hope, therefore, soon to try another form, already suggested by one of us, such that the heat will be less rapidly diffused.

NORTHWESTERN UNIVERSITY, EVANSTON, ILL.,
February 8, 1898.

FIGURE 10. Reduced one half.

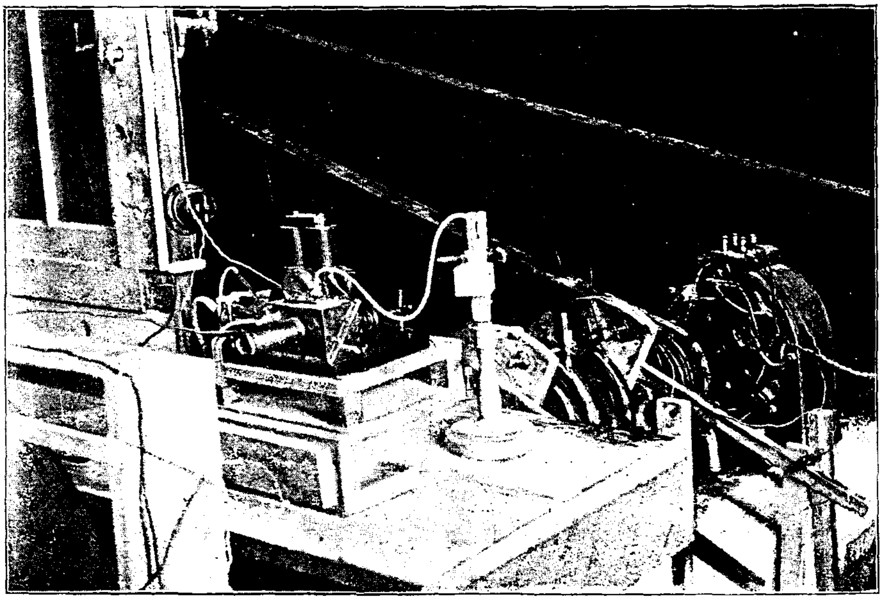

FIGURE 11.

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AN ABSOLUTE MEASUREMENT OF THE THOMSON EFFECT IN COPPER.

By R. O. King, B. A. Sc.

Exhibition of 1851 *Scholar.*

Investigations on Light and Heat, made and published wholly or in part with Appropriation from the Rumford Fund.

AN ABSOLUTE MEASUREMENT OF THE THOMSON EFFECT IN COPPER.

By R. O. King, B. A. Sc.,
Exhibition of 1851 *Scholar.*

Presented April 13, 1898, by E. H. Hall.

The experiments described in this paper were carried out at the Jefferson Physical Laboratory of Harvard University, under the supervision of Dr. E. H. Hall. A grant of one hundred dollars was obtained from the Rumford Fund of the American Academy of Arts and Sciences for the purchase of apparatus. The principle of the method employed in the experiments was devised by Prof. H. L. Callendar, M. A., F. R. S., of McGill University, and depends on the measurement of change of temperature by means of change of electrical resistance.

Historical.

In 1856 Lord Kelvin published * the details of an experiment which showed the existence of a new phenomenon, which has since been called the Thomson Effect. Aside from the interest always attached to a discovery, the Thomson effect possessed an additional interest due to the fact that, two years before, Lord Kelvin had inferred its existence by the application of the laws of thermo-dynamics to thermo-electric circuits. In spite of the great interest taken in the Thomson Effect at that time, very few attempts have been made to obtain an absolute measurement of it, or to examine its dependence on temperature conditions. This can probably be explained by its extreme smallness and difficulty of measurement.

Lord Kelvin in his original experiments sought only to prove the existence of the "electric convection of heat." The metals used in the principal experiments were iron and copper. The effect in iron was found to be considerably greater than in copper. No absolute measurements of the effect were attempted.

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* Royal Society of London, Phil. Trans., 1856.

Le Roux * in 1867 confirmed the results of Lord Kelvin. Working with a more sensitive apparatus, he obtained relative values of the Thomson Effect in several metals, and was able to show that, with a given gradient of temperature, the effect, as expected, was directly proportional to the current.

Tait, in deducing a formula to express the relation between the e. m. f. of a thermo-electric couple and the difference in temperature of the junctions, assumed that the Thomson Effect was directly proportional to the absolute temperature. The relation deduced in this way agrees very well but not exactly with the results of most experiments. In some recent experiments in which a Callendar Platinum Resistance Thermometer was used, Mr. H. M. Tory † has found a regular deviation of the experimental results from the results as given by Tait's formula.

Batelli ‡ has made absolute measurements of the Thomson Effect for a number of metals, and has found that in most cases Tait's assumption is approximately verified. As Batelli's is the only work I have found on the absolute measurement of the Thomson Effect, it is worth while to examine his method closely and to point out the possible sources of error.

Batelli prepared two rods of the metal in which the Thomson Effect was to be measured, about 30 cm. long and 0.5 cm. in diameter. One end of each rod projected into a heating bath H, the other end into a cooling bath, C, Fig. 1. There was then a flow of heat through the rods from the hot to the cold bath. The rods passed through iron boxes B_1 and B_2, 4 cm. long, containing mercury, which served as calorimeters.

When an electric current was passed up one rod and down the other, that is with and against the flow of heat in B_1 and B_2, respectively, the Thomson Effect liberated heat from one bar and absorbed it in the other. This caused the temperature of one calorimeter to rise above, that of the other to fall below, the mean temperature of the calorimeters when no electric current was flowing. From the difference in temperature of the calorimeters measured with a thermo-electric couple and the water equivalent of the calorimeters, Batelli calculated the sum of the heat liberated and absorbed in a given time by the Thomson Effect.

The method of working was as follows. The temperature of the rods was allowed to reach a steady state before the electric current was

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* Annales de Chimie et de Physique. 1867.

† British Association Report. 1897.

‡ Atti della Reale Accademia delle Scienze di Torino. 1886.

applied, the mercury in the calorimeters being violently agitated meanwhile and throughout the whole experiment. (1) Readings of the difference of temperature of the calorimeters were taken at half-minute intervals for twenty minutes with no electric current flowing. (2) Readings were taken at like intervals for the same time with a known electric current flowing. (3) Readings were taken as before for twenty minutes with no current flowing.

From these three sets of observations, the actual difference in temperature between the calorimeters due to the heat liberated in one and absorbed in the other could be found. This difference in temperature between the calorimeters reached in 20 minutes, deduced from the three sets of observations as described above, is multiplied by the water equivalent of the calorimeters; the product is divided by the number of seconds in 20 minutes, by the difference in temperature between the ends of the calorimeters, that is between the points *a* and *b*, Fig. 1, by the electric current in c. g. s. measure, and by 2 to allow for the reversal of the current.

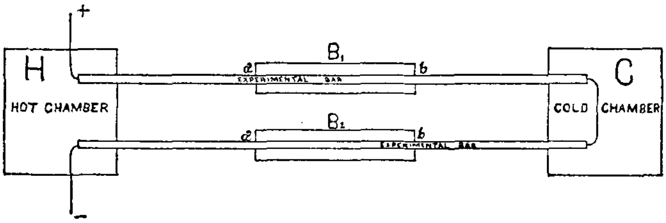

FIGURE 1.

In a set of six experiments on Cadmium made as described above, the difference in temperature obtained between the calorimeters ranged between 0°.0122 C. and 0°.0085 C. The difference of temperature between the ends *a*, *b*, of the calorimeters measured in the bar was 21°.0 C.

There are two great difficulties in Batelli's method. (1) It is necessary to measure accurately a mean difference of 0°.012 C. between boxes of mercury, each of which surrounds a part of a bar in which there exists a difference of temperature of 21°.0 C. It seems likely that in spite of violent stirring considerable differences of temperature would be found in the mercury. (2) The presence of the violently agitated mercury in the calorimeter tends to destroy the temperature gradient in the rod, on which the Thomson Effect depends. In fact, it seems that the best result in the measurement of the difference of temperature between the calorimeters would be attained only when the mercury was sufficiently agitated to make the temperature of the part of the bar surrounded by the calorimeter uniform and the Thomson Effect consequently zero. It also follows that the value obtained for the Thomson Effect would depend on the rate of stirring of the mercury. The variation between the several values found for the difference in temperature between the calorimeters sometimes, as in the specimen quoted above, amounts to 50%. It would seem from this that the difficulties mentioned above are real.

Two points of less importance are: (1) No correction was made for the change in the heat liberated by the Joule Effect due to the change in temperature, and hence in resistance of the part of the rods in the calorimeters. (2) No correction was made for the change in the rate of heat conducted into or out of the calorimeters, due to the slight change in the temperature gradient caused by the action of the Thomson Effect.

General Description of Method of this Paper.

The ends of the copper wire, in which the Thomson Effect was to be measured, were fastened into copper blocks provided with a water circulation to keep them at a constant temperature. The copper wire was heated by an electric current. There was then a flow of heat from the middle of the wire to each end. In one half of the wire this flow of heat was opposite in direction to the flow of electricity, in the other half it was in the same direction. Consequently in one half of the wire the Thomson Effect liberated heat and in the other half absorbed it. On reversing the electric current the effect was of course reversed. By measuring the change of resistance of short sections of the wire on reversal of the current, it was possible to determine the change of temperature. By a separate experiment, with the same apparatus, the relation between the heat lost by radiation and convection from any part of the wire and the temperature of that part was determined. With these data, considering any part of the wire made up of a whole number of sections, the following quantities could be determined. (1) The change in the heat generated by the Joule Effect on reversal of the electric current. (2) The change in the heat lost by radiation and convection on reversal. (3) The change in the heat conducted out of the cold end of the part of the wire under consideration on reversal. (4) The change in the heat conducted in at the hot end on reversal. These quantities suffice for the absolute measurement of the Thomson Effect.

General Description of the Apparatus.

The copper wire $a\,b$ is soldered into holes in the copper blocks B_1, B_2, Fig. 2. A brass tube, T, is slipped over the blocks and the rubber rings r_1, r_2, r_3, r_4. This tube has its sides cut away opposite the wire $a\,b$; but the ends are left whole, so that, by means of them and of the rubber rings, jackets, through which a water circulation can pass, are formed around the copper blocks. The leads, 3, 4, 5, etc. are of no. 40 B. & S. copper wire and are fastened to the bar $a\,b$ by an electrolytic deposit of copper. These fine leads are led through holes in the part of the brass tube T not cut away, and through a hard rubber strip, R, to copper binding posts on the base board. The small tube t can be unscrewed and a water jacket, slotted longitudinally to allow the rubber strip R and the fine leads to pass, slipped over the tube T. So that during an experiment the surroundings of the experimental wire can be kept at a constant temperature. The electric current for heating the wire is brought in by the mercury cups in the ends of the blocks B_1, B_2. Copper leads are clamped on these blocks at E_1 and E_2 and are connected to the resistance boxes A and B and cylinder potentiometer as shown in Fig. 2. One terminal, g_2, of a sensitive low resistance galvanometer is connected to the movable contact of the potentiometer; the other, g_1, can be connected with any one of the leads 3, 4, 5, 6, etc.

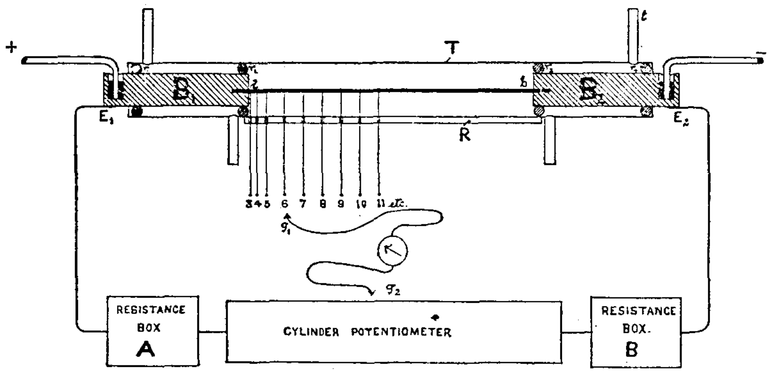

FIGURE 2.

Working of the Method.

Suppose the wire $a\,b$ is heated by the electric current and that the blocks B_1 and B_2 and the surroundings have reached a steady temperature. By adjusting the resistance in A and B the potentiometer can be made to correspond to the resistance of any section of the experimental wire. For instance, suppose the galvanometer lead g_1 is connected with lead no. 9, and that under these circumstances a balance of the galvanometer is obtained with g_2 reading nearly 100 on the potentiometer; then suppose that a balance for no. 8 is obtained at nearly 0 on the potentiometer. The difference between the potentiometer readings, that is, nearly the whole length of the potentiometer, will then correspond to the resistance of the section 8 to 9. Repeating the operation with the heating current in the opposite direction, a somewhat different length on the potentiometer will be found to correspond to the resistance of the section 8 to 9. The difference between these two lengths corresponds to the change of resistance of section 8 to 9 on the reversal of the current, on the same scale that the mean of the two lengths corresponds to its absolute mean resistance. Hence the change of temperature of any section of the wire, on reversal of the current, can be calculated. Also if the mean absolute resistance be determined, from a separate experiment, the absolute change of resistance and hence the difference in the rate of generation of heat, by the mere overcoming of resistance, in section 8 to 9, on reversal of the current, can be calculated. If from another experiment the relation between h, the heat dissipated by radiation and convection from any part of the surface of the wire, and the temperature of that part be known, then the difference in the rate of dissipation of heat by the section on reversal of the current can be calculated. There remains, for the complete determination of the Thomson Effect in section 8 to 9, to be found the change in the temperature gradients at the points 8 and 9, due to the small change of temperature on the reversal of the current.

Let us suppose that by the method described above the change of temperature on reversal of the current has been found for every section of the bar, i. e. 3 to 4, 4 to 5, 5 to 6, etc. If the results are plotted a curve such as $c\,d$, Fig. 3, is obtained. Let the curve $a\,e$ represent the distribution of temperature along the wire. The curve $c\,d$ and $a\,e$ are drawn to different scales. When the largest ordinate of $a\,e$ was 235° that of $c\,d$ was about 1°.2. The curve $c\,d$ being a temperature difference curve for corresponding points on $a\,e$, a little reflection will show that the tangent to $c\,d$ at any point, measured in degrees per cm., will be the change in the tangent to $a\,e$ at the corresponding point, on the reversal of the current. Hence by multiplying this difference tangent by the area of cross section of the bar and by the thermal con-

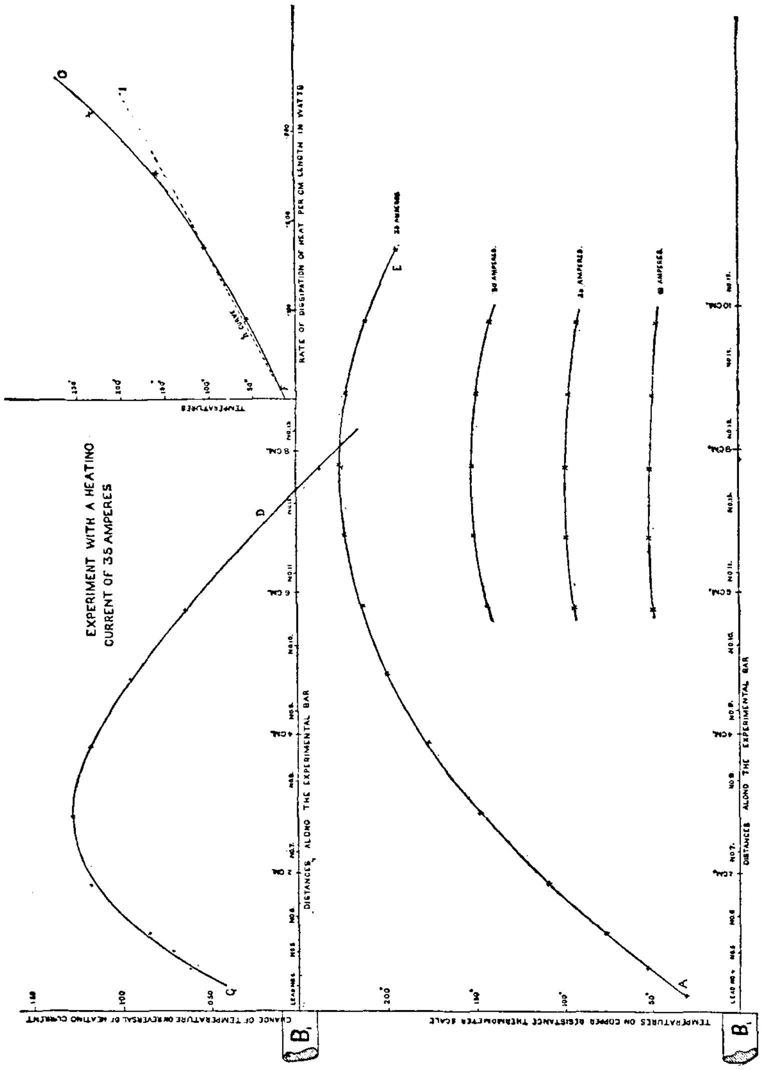
EXPERIMENT WITH A HEATING CURRENT OF 35 AMPERES
RATE OF DISSIPATION OF HEAT PER CM LENGTH IN WATTS
TEMPERATURES
DISTANCES ALONG THE EXPERIMENTAL BAR
TEMPERATURES ON COPPER RESISTANCE THERMOMETER SCALE
CHANGE OF TEMPERATURE ON REVERSAL OF HEATING CURRENT
35 AMPERES
30 AMPERES
20 AMPERES
10 AMPERES
A
C
D
E
O
B
B

FIGURE 3.

ductivity at the point of the bar under consideration, it is possible to calculate the change in the amount of heat conducted past any point on reversal of the heating current. In this way the change in the amount of heat conducted out at No. 8 and No. 9 would be determined.

In practice it is advisable to use more than one short section in determining the Thomson Effect. In the experiment as set up the sections were made about 1 cm. in length, with the exception of some half as long near the ends. A part of the wire comprising at least four sections was used in calculating the value of the Thomson Effect.

For convenience of reference, let the quantities used in calculating the Thomson Effect be designated as follows: —

Let x_1 and x_2 be any two points on the experimental wire, whose temperatures are θx_1 and θx_2.

Let σ be the Thomson Effect coefficient defined by the relation $\sigma(\theta x_1 - \theta x_2)$ = heat developed in x_1 to x_2 when one c. g. s. unit of electricity passes from x_1 to x_2.

Let $R x_1 x_2$ = resistance of section (x_1 to x_2), current entering B_2.

Let $H x_1 x_2$ = heat dissipated from (x_1 to x_2), current entering B_2.

Let $k x_1 \left(\frac{d\theta}{dx}\right)$ = heat conducted past x_1 out from section, current entering B_2.

Let $k x_2 \left(\frac{d\theta}{dx}\right)$ = heat conducted past x_2 into section, current entering B_2.

Let the same letters with dashes represent similar quantities when the current enters B_1.

Let Υ = the electric current in amperes.

Then: —

$$2\sigma\,(\theta x_2 - \theta x_1)\frac{\Upsilon}{10} = (H^1 x_1 x_2 - H x_1 x_2) - \Upsilon^2\,(R^1 x_1 x_2 - R x_1 x_2)$$
$$+ k x_1\left[\left(\frac{d\theta}{dx}\right)^1 - \left(\frac{d\theta}{dx}\right)\right] - k x_2\left[\left(\frac{d\theta}{dx}\right)^1 - \left(\frac{d\theta}{dx}\right)\right].$$

The Curve of Distribution of Temperature.

This curve has been referred to as *a e*, Fig. 3, and is obtained from a separate experiment with the same apparatus, with the exception that a standard low resistance is required in addition. The determination of this curve involved the measurement of the resistance of the short sections of the experimental wire, (1) when a current small enough not to heat the wire appreciably was flowing, (2) when the heating current Υ was flowing. From the change of resistance due to the heating current the change of temperature was calculated. The standard low resistance was included, with the experimental wire, between the terminals of the potentiometer, as shown in Fig. 4.

The galvanometer was balanced, see Fig. 4, with the terminal g_1 connected with 1, 2, 3, 4, 5, etc., successively, by adjusting the position of the contact g_2 on the potentiometer. The relation of the differences between the potentiometer readings, corresponding to 3, 4, 5, 6, etc., to the difference between the readings for 1 and 2, expresses the relation of the resistances of sections 3 to 4, 4 to 5, 5 to 6, etc., to the resistance of the standard S.

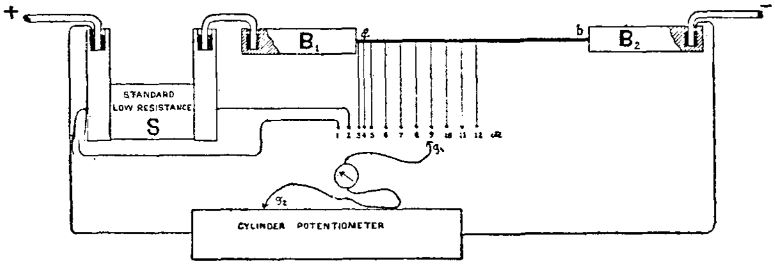

Figure 4.

Determination of the h Curve, f g (Fig. 3).

If the experimental wire *a b* be long enough, the curve of distribution of temperature will be flat for the part corresponding to the middle of the bar. That is, the middle section will not be losing heat by conduction to the neighboring parts of the bar. Therefore the heat generated by the Joule Effect in the middle section will be all got rid of by radiation and convection. By measuring the resistance of the middle section and the electric current in amperes, under the above conditions, the heat generated, as well as the temperature, for the section can be calculated. By using several values for the electric current, different temperatures are obtained for the middle of the bar and corresponding values for the heat dissipated by radiation and convection. This gives all the data required for the determination of the *h* curve, provided we assume that the condition of the surface of the bar is uniform and that all parts of the bar are affected in the same way by convection currents.

In the experiments described in this paper the experimental bar was too short to avoid the effect of metallic conduction on the middle section, so that a correction had to be made for the heat thus carried off. A knowledge of the temperature gradients at the ends of the section and the thermal conductivity was required for the application of this correction. Different observers have obtained very different values for the thermal conductivity of copper; therefore, in order to see what effect an error in the estimation of this quantity would have on the final value for the Thomson Effect, the part of the work depending on this has been worked through with two different values.

Precautions against Thermo-electric Effects at the Junctions of Dissimilar Metals.

The average resistance of a section of the experimental bar was about 0.00022 ohm. In the measurement of so small a resistance, and particularly the change in this resistance on reversal of the heating current, it was extremely important to avoid errors due to thermo-electric disturbances at junctions of dissimilar metals. The potentiometer was specially designed for the experiment and was made of 100 turns of manganine wire wound on a marble cylinder. All connections to the manganine were of copper and the instrument was completely enclosed in a glass covered box. All adjustments of the contact point could be made without opening the box. The resistance boxes A and B, Fig. 2, were also enclosed in glass covered boxes.

The fine potential leads, 3, 4, 5, etc., Fig. 2, were copper and were copper-plated to the experimental bar. The connection with the potentiometer was made through copper binding posts. The galvanometer key and circuit were entirely of copper.

It was found that copper and manganine form a thermo-electric couple only about one eighth as strong as copper and German silver, hence the choice of manganine for the potentiometer wire.

The Heating Current.

In the experiment on the change of resistance on reversal of the current, it was very important that the current used for heating the wire should be kept very nearly constant, since a change in it would cause a change in the temperature of the bar and hence in the resistance of any section. If this change were confounded with the change due to the Thomson Effect, serious error would result. The following arrangement for measuring and regulating the current was found to be very satisfactory.

A mercury trough resistance, a rough tin plate resistance and a Kelvin current balance were included in the circuit of the heating current. The mercury trough resistance was capable of being varied continuously by means of amalgamated sliding copper contacts. The slider on the Kelvin balance being set to read the desired current, the pointer on the balance arm was kept exactly at the middle mark throughout the experiment, by adjusting the sliding contacts of the mercury trough resistance. The current was drawn from ten one-hundred-ampere hour accumulators in parallel, specially set up for the experiment.

The Standard Low Resistance.

This was specially made for the experiment and consisted of four sheets of manganine in parallel between heavy copper terminals. The resistance of the standard was .000733 ohm, so that with the largest current used, that is, 35 amperes, heat was generated at the rate of about one watt. For the dissipation of this energy there was a surface of about 275 square cm. immersed in oil through which there was a good water circulation.

The Experimental Bar and Potential Leads.

The bar was of best quality copper magnet wire. Chemical analysis showed a percentage of 99.3 copper.

The length between the blocks B_1 and B_2 was 15.6 cm. The diameter was somewhat irregular, as shown by the following: —

	End.	Half-way.	Middle.	Half-way.	End.
Vertical diam.	.0952	.0960	.0956	.0962	.0966 cm.
Horizontal "	.0954	.0966	.0960	.0966	.0970 "

The bar was annealed and its surface blackened by dipping, while hot, in an acid solution of silver nitrate.

Nineteen potential leads of no. 40 B. & S. copper wire were copper plated to the bar. Their positions were as below: —

No. of Lead.	Distance from B.	Name of Section.	Length of Section.	No. of Lead.	Distance from B.	Name of Section.	Length of Section.
3	0.00 cm.	. . . .	. . . .	12	7.26 cm.	11 to 12	.99 cm.
3½	0.06 "	3 to 3½	.06 cm.	13	8.27 "	12 to 13	1.01 "
4	0.37 "	3½ to 4	.31 "	14	9.28 "	13 to 14	1.01 "
5	0.86 "	4 to 5	.49 "	15	10.28 "	14 to 15	1.01 "
6	1.38 "	5 to 6	.52 "	16	11.30 "	15 to 16	1.02 "
7	2.31 "	6 to 7	.93 "	17	12.30 "	16 to 17	1.00 "
8	3.35 "	7 to 8	1.04 "	18	13.28 "	17 to 18	.98 "
9	4.33 "	8 to 9	.98 "	19	14.30 "	18 to 19	1.02 "
10	5.25 "	9 to 10	.92 "	20	14.80 "	19 to 20	.50 "
11	6.27 "	10 to 11	1.02 "	21	15.28 "	20 to 21	.48 "

Calculation of the Temperature.

In estimating changes of temperature by means of changes of resistance, using Callendar's method,* it is necessary to know the average value of the temperature coefficient for the copper between 0° and 100°, or the ratio $\frac{R_1}{R_0}$.

Where

$$R_1 = \text{resistance at } 100^\circ \text{ C.},$$
$$R_0 = \text{resistance at } 0^\circ \text{ C.}$$

Let $R =$ the observed resistance.
Let $Cu =$ temperature on copper resistance scale.
Let $t =$ temperature on air thermometer scale.

The ratio $\frac{R_1}{R_0}$ was taken $= 1.422$.

Temperatures are calculated according to the formula

$$Cu = \frac{R - R_0}{R_0} \times \frac{100}{\frac{R_1}{R_0} - 1} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

---

* H. L. Callendar, Phil. Trans., 1887.

The relation between temperatures on the air thermometer scale and temperatures by the copper resistance thermometer is expressed by the formula

$$t - Cu = \delta \left\{ \left(\frac{t}{100}\right)^2 - \frac{t}{100} \right\} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The value of δ was taken $= 1.32$. The values of $\frac{R_1}{R_0}$ and δ given here were found in some experiments on copper magnet wire made two years ago. A small inaccuracy in the value of these constants is not important for the work described in this paper; so it was not considered necessary to determine them for the wire actually used.

The copper resistance thermometer and air thermometer scales agree, of course, at 0° and 100°; but at all other temperatures within the range of work described here there is a slight divergence, perhaps enough to make it worth while to take it into account.

EXPERIMENT WITH A HEATING CURRENT OF 35 AMPERES.

Distribution of Temperature along the Bar.

This was determined as described on page 360 the resistance of the sections of the bar being measured in terms of the standard S, Fig. 4. (1) With the heating current of 35 amperes. (2) With a current of 2 amperes. It was assumed that the current of 2 amperes did not raise the temperature of the bar above that of its surroundings. It will be seen that this assumption is allowable when we consider that 35 amperes heated the bar to a temperature of about 220°, and that the heating is proportional to the square of the current.

Referring to page 369, column V. gives the observed resistances of the sections of more than half the bar, with a current of 2 amperes, and consequently at the temperature of the surrounding water jackets, that is 11°.9 C. = 12°.1 *Cu*. Column VI. gives the observed resistances with the heating current of 35 amperes. Column IV. gives R_0, the calculated value of the resistance of each section at 0°. This is found from the resistance at 12°.1 *Cu*, the ratio $\frac{R_{12.1}}{R_0}$ being taken $= \frac{1 + 12.1 \times .00422}{1}$. Column IX. gives the temperature of each section calculated by the formula

$$Cu = \frac{R - R_0}{R_0} \times \frac{100}{\frac{R_1}{R_0} - 1}.$$

The temperatures found thus are plotted, *a e*, Fig. 3, and give a very smooth curve.

The Change of Resistance of the Sections on Reversal.

This change was measured for all the sections from lead no. 4 to lead no. 14, according to the general method as described on page 358. In order to show the exact way of taking the observations, the readings for one section are given in full below. The other sections are given only in abstract below.

Take section (9 to 10). With 72 ohms in resistance box A and 200 ohms in box B, potential lead no. 9 balanced near the zero end of the potentiometer and no. 10 near the 100 end. The readings are marked, to show the order in which they were taken, by the small numbers in parentheses.

	Lead No. 9.	Direction of Current.	Lead No. 10.	Direction of Current.
	5.412 (1)	S	91.200 (2)	S
	4.447 (3)	N	90.044 (4)	N
	5.418 (5)	S	91.208 (6)	S
	5.453 (7)	N	90.050 (8)	N
	5.422 (9)	S	91.204 etc.	S
	4.451	N	90.050	N
	5.412	S	91.204	S
	4.451	N	90.046	N
	5.422	S	91.202	S
Means :				
	5.417	S	91.204	S
	4.450	N	90.050	N
Means, plus calibration correction of potentiometer :				
	5.455	S	91.241	S
	4.488	N	90.089	N

Hence a length on the potentiometer of 91.241 — 5.455 = 85.786 represents the resistance of section 9 to 10 when the current is in the S. direction, and a length 90.089 — 4.488 = 85.601 represents the resistance when the current is in the N. direction. So that the difference between these lengths, that is 85.786 — 85.601 = 0.185, represents the change of resistance on reversal of the current on the same scale that the mean of the lengths, i. e. 85.69, represents the actual resistance of the section. From column VI., page 369, the mean value of the resistance of section 9 to 10 when carrying 35 amperes is seen to be 0.0003781, so that the absolute change in resistance on reversal is

$$\frac{.185}{85.69} \times .0003781 = .000000817 \text{ ohm.}$$

From column IV, the resistance of the section at 0° is seen to be 0.00020304, hence the change of temperature corresponding to the above change of resistance

$$= \frac{.000000817}{.00020304 \times .00422} = 0^\circ.955 \; Cu.$$

The several quantities discussed above, that is, the potentiometer turns representing the whole resistance of the several sections, the turns representing the change of resistance, the actual change of resistance in ohms, the corresponding change of temperature in degrees, are tabulated in columns II., III., VII., VIII., respectively.

The numbers representing the change of temperature on reversal, for the several sections when plotted, give the curve *c d*, Fig. 3.

The h Curve.

Observations were taken on the five middle sections of the bar, using heating currents of 35, 30, 25, and 18 amperes, in order to obtain short lengths of the temperature distribution curve at several temperatures. Unfortunately the specimen was not long enough to avoid metallic conduction of heat from the middle section, so that all the heat generated in this section is not lost by radiation and convection. The slight temperature gradient at the ends of the middle section, 12 to 13, is shown in Fig. 3.

Length of section 12 to 13 = 1.01 cm.
Mean area of cross section = .00720 sq. cm.
The thermal conductivity = $.870\,(1 + .0004\,t)$.[*]

With the above data and the temperature gradients at the ends of the section, measured graphically, the amount of heat conducted away from the section for the several values of the heating current is obtained.

The following table gives the data required for the plotting of the *h* curve: —

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[*] From some unpublished experiments.

Temperature of the Section.	Resistance of the Section.	Current in Amperes.	Rate of Heat generated, Watts.	Same per cm.	Rate of Heat conducted, Watts.	Rate of Heat dissipated per cm. length.
233.4	.0004480	35.0	.538	.533	.215	.318
157.9	.0003763	30.0	.339	.336	.084	.252
105.0	.0003259	25.0	.204	.202	.033	.169
56.9	.0002800	18.0	.091	.090	.000	.090

Plotting the values found for the rate of dissipation of heat as abscissas and the corresponding values of the temperature as ordinates, the curve *f g*, Fig. 3, is obtained.

Determination of the Change in the Rate of Dissipation of Heat by Radiation and Convection on Reversal of the Heating Current.

From the *h* curve, described in the last paragraph, and the curve of distribution of temperature along the bar, the condition of any section of the bar as regards temperature and rate of dissipation of heat can be obtained. If now the temperature of a section be slightly changed, the corresponding change in the rate of dissipation of heat can be determined by simple proportion, since the *h* curve is nearly a straight line. The change of temperature on reversal of the heating current has been already determined for all the sections of the part of the bar under consideration; so it is a very simple matter to calculate the change in the rate of dissipation of heat, on reversal of the current, for any section of the bar.

Column IX., page 369, gives the mean temperature of every section of the part of the bar under consideration. Column X. gives the corresponding rate of dissipation of heat from the surface of the bar, as obtained from the *h* curve. The change in the rate of dissipation for the several sections is tabulated in column XI. From this column the quantity $H^1 - H$, see page 369, can be at once obtained for any part of the bar consisting of a whole number of sections.

I. Section.	II. Potentiometer Turns representing Resistance of Section.	III. Turns representing Change of Resistance.	IV. Ro.	V. Resistance at 2 Amperes.	VI. Resistance at 35 Amperes.	VII. Change of Resistance on Reversal.	VIII. Change of Temperature on Reversal.	IX. Mean Temperature.	X. Mean Rate of Dissipation of Heat.	XI. Change in Rate of Dissipation of Heat on Reversal.
4 to 5	62.15	.135	.00010412	.00010943	.00012780	.000000277	0.630	53.9	.041	.00048
5 to 6	77.63	.211	.00011723	.00012321	.00015590	.000000424	0.857	78.2	.066	.00072
6 to 7	79.55	.269	.00020430	.00021471	.00030078	.000001018	1.182	111.9	.169	.00179
7 to 8	87.34	.290	.00022160	.00023615	.00036774	.000001219	1.283	151.0	.246	.00209
8 to 9	85.10	.242	.00021180	.00022195	.00037204	.000001058	1.186	180.5	.267	.00175
9 to 10	85.69	.185	.00020304	.00021340	.00037809	.000000817	0.955	204.3	.274	.00128
10 to 11	95.42	.135	.00022005	.00023128	.00042354	.000000599	0.645	219.1	.318	.00094
11 to 12	95.90	.091	.00022369	.00023510	.00044062	.000000401	0.425	229.8	.325	.00060
12 to 13	89.87	.026	.00022572	.00023724	.00044801	.000000130	0.136	233.4	....	....
13 to 14	85.50	.101	.00021797	.00022909	.00042912	.000000506	—.550	230.1	....	....
14 to 15	....	....	.00021746	.00022854	.00041863	....	....	219.2	....	....

Evaluation of the Thomson Effect.

I. Consider the sections from lead no. 4 to lead no. 12. 4 and 12 may replace x_1 and x_2 (see page 360).

Then : —

(1) $\underset{4\text{ to }12}{R^1} - \underset{4\text{ to }12}{R} = .000005813$ (from column VII., page 369). $\Upsilon = 35$;

hence $\Upsilon^2 \left(\underset{4\text{ to }12}{R^1} - \underset{4\text{ to }12}{R}\right) = 35^2 \times .000005813 = .00713$ watts.

(2) $\underset{4\text{ to }12}{H^1} - \underset{4\text{ to }12}{H} = .00965$ (from column XI., page 369).

(3) The change in the temperature gradient at no. 4 on reversal of the heating current, determined from curve *c d*, Fig. 3, $= 0°.752$ per cm.

Area of cross section at no. $4 = .00713$ sq. cm.

The thermal conductivity at no. $4 = .89$, on the assumption that thermal conductivity $= .87\ (1 + .0004\ t)$.

Hence $k_4 \left[\left(\frac{d\,\theta}{d\,x}\right)^1 - \left(\frac{d\,\theta}{d\,x}\right)\right] = .752 \times .00713 \times .89 \times 4.2 = .0200$ watts

Similarly $k_{12} \left[\left(\frac{d\,\theta}{d\,x}\right) - \left(\frac{d\,\theta}{d\,x}\right)^1\right] = -.400 \times .00724 \times .95 \times 4.2 = -.0116$ watts.

The temperature at no. $4 = 41°$.

The temperature at no. $12 = 232°$.

Hence the difference of temperature between the ends of the section is 191°. Substituting in the equation of page 360, we have

$$2\ \sigma\ (232 - 41) \times 3.5 = .00965 - .00713 + .0200 - (-.0116)$$

$$\therefore \sigma = \frac{.00965 - .00713 + .0200 + .0116}{2 \times 3.5 \times 191} = .00002553 \text{ watts.}$$

$$= .00000608 \text{ calories per second.}$$

Mean temperature of section $= 116°$ C.

Expressing the result exactly : — When an electric current of 10 amperes flows, in the same direction as the flow of heat, for 1 second through a section of a copper bar whose ends differ by 1° C. and whose mean temperature is 116° C., the Thomson Effect will be represented by the liberation of .00000608 calories.

The work of calculating the value of the Thomson Effect for other parts of the bar at different temperatures is precisely similar to the above; so a summary only is given in the following table : —

Section.	$k_{x_1}\left[\left(\frac{d\theta}{dx}\right)^1-\left(\frac{d\theta}{dx}\right)\right]$	$k_{x_2}\left[\left(\frac{d\theta}{dx}\right)-\left(\frac{d\theta}{dx}\right)^1\right]$	H^1-H
4 to 12	0.0200	– 0.01160	0.00965
6 to 12	0.01132	– 0.01160	0.00845
7 to 12	0.00356	– 0.01160	0.00666
8 to 12	— 0.00291	– 0.01160	0.00457

Section.	$Y^2(R^1-R)$	$\theta_{x_2}-\theta_{x_1}$	Mean Temperature.	σ
4 to 12	0.00713	191°	166°	.00000608
6 to 12	0.00626	141°	183°	.00000606
7 to 12	0.00500	101°	197°	.00000566
8 to 12	0.00352	65°	208°	.00000508

The values of the Thomson Effect deduced above decrease with an increase of temperature. This is, of course, contrary to the accepted view. It is, then, important to determine to what extent the necessary errors of the method used affect the result.

It is probably apparent to the reader that the most serious errors are likely to be found in the estimation of the thermal conductivity and in the determination of the *h* curve. As already explained, on account of the shortness of the experimental bar a large correction has to be applied for the conduction of heat from the middle section of the bar in the determination of the *h* curve. However, this correction is not so large that a considerable error in the estimation of the thermal conductivity would affect the value of the *h* curve within the limits of accuracy of this work.

The form of the *h* curve, *f g*, Fig. 3, was unexpected. It was thought that it would be either straight or bent downwards at the higher temperatures. In some experiments made two years ago at McGill University, a number of "*h* curves" were obtained for bars under similar conditions and in all cases they were very nearly straight. Taking, then, the dotted line *f i*, Fig. 3, to be the *h* curve, and taking its inclination from the lower points, the portion of the Thomson Effect determination affected by this change has been reworked. The results are given in column II. of the following table.

Any error in the value taken for the thermal conductivity is directly felt in the determination of the change in the rate of heat conducted in and out of the ends of the sections, on reversal of the heating current. For this reason, the value of the thermal conductivity of copper determined recently by R. W. Stewart,* namely 1.12 (1 — .001 t), has been applied to the Thomson Effect calculations. This value of the thermal conductivity differs very much from that previously used, the temperature coefficient also, being of the opposite sign. The values of the Thomson Effect as modified by this change are given in column III. below.

Mean Temperature of Sections.	I. Original Values, from page 371.	II. Values, assuming h curve to be a straight line.	III. Values, as in II., but also taking thermal conductivity = 1.12 (1 — .001 t).
166°	.00000608	.00000623	.00000678
183°	.00000606	.00000630	.00000637
197°	.00000566	.00000600	.00000564
208°	.00000508	.00000551	.00000493

It seems to be unlikely that the decrease in the Thomson Effect with rise of temperature can be accounted for by even large variations in the form of the h curve or in the value of the thermal conductivity.

A good criterion of the general accuracy of the whole scheme of the experiment is the calculation of the thermal conductivity from the several quantities involved.

Consider section 4 to 12: — The temperature gradient, $\frac{d\,Cu}{d\,x}$, at no. 4, measured on the curve, $a\,e$, Fig. 3, is 53°.6 $Cu.$ per cm. This must be reduced to degrees Centigrade per cm.

From equation (2), page 365, differentiating we have

$$\frac{d\,t}{d\,Cu} = \frac{1}{1 - .0132\,(.02\,t - 1)}.$$

At no. 4, $t = 41$; hence $\frac{d\,t}{d\,Cu} = \frac{1}{1.024}$, therefore $\frac{d\,t}{d\,x} = \frac{53.6}{1.024} = 52.3$.

Let $K =$ the thermal conductivity at no. 4, i. e. at 41°. Then section 4 to 12 is losing heat by conduction at no. 4 at the rate of

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* Phil. Trans. Roy. Soc. Lond. 1895.

$K \times 52.3 \times .00714 \times 4.2$ watts, .00714 being the area of cross section in sq. cm., and 4.2 expressing the relation between calories and watts.

The resistance of section 4 to 12 is .0025660 ohms, see page 369, column VI. Hence heat is being generated at the rate of $35^2 \times .0025660 = 3.145$ watts.

The rate at which heat is dissipated from section 4 to 12, by radiation and convection = 1.706 watts (see page 369, column X.), if *f g*, Fig. 3, be taken as the *h* curve.

On the assumption that the *h* curve is straight, heat would be dissipated at the rate of 1.951 watts.

A small quantity of heat flows into the section at no. 12. It amounts to .1070 watts.

Collecting the quantities, we have

$$K \times 4.2 \times .00714 \times 52.3 = 3.145 + .1070 - 1.706.$$

$$\therefore K = \frac{1.546}{4.2 \times .00714 \times 52.3} = .98 \text{ c.g.s. units.}$$

Taking *f i*, Fig. 3, as the *h* curve, we should have $K = .83$ c.g.s. units.

The closeness of these values to the generally accepted ones is a good test of the general accuracy of the work, especially when it is considered that the experiment was not designed with a view to determining the thermal conductivity.

EXPERIMENT WITH A HEATING CURRENT OF 30 AMPERES.

This experiment was made on the end of the bar which had not been used in the experiment with 35 amperes, in order to see what effect a considerable change in the important quantities involved in the work would have on the results.

The data required for the calculation of the value of the Thomson Effect are tabulated on page 375.

The distribution of temperature along the bar was determined in the same way as before and a very smooth curve obtained, see *a e*, Fig. 5. The temperatures, column X., page 375, are calculated from the resistances given in columns IV. and VI.

The change of temperature of the sections on reversal of the heating current is considerably smaller than for the experiment with 35 amperes and the curve *cd*, Fig. 5, is not as good as the corresponding one in Fig. 3. The curve *cd* is plotted from the figures in column VIII. The quantities in column IX., from which the change in the rate of heat dissipated is obtained, are taken from the smooth curve.

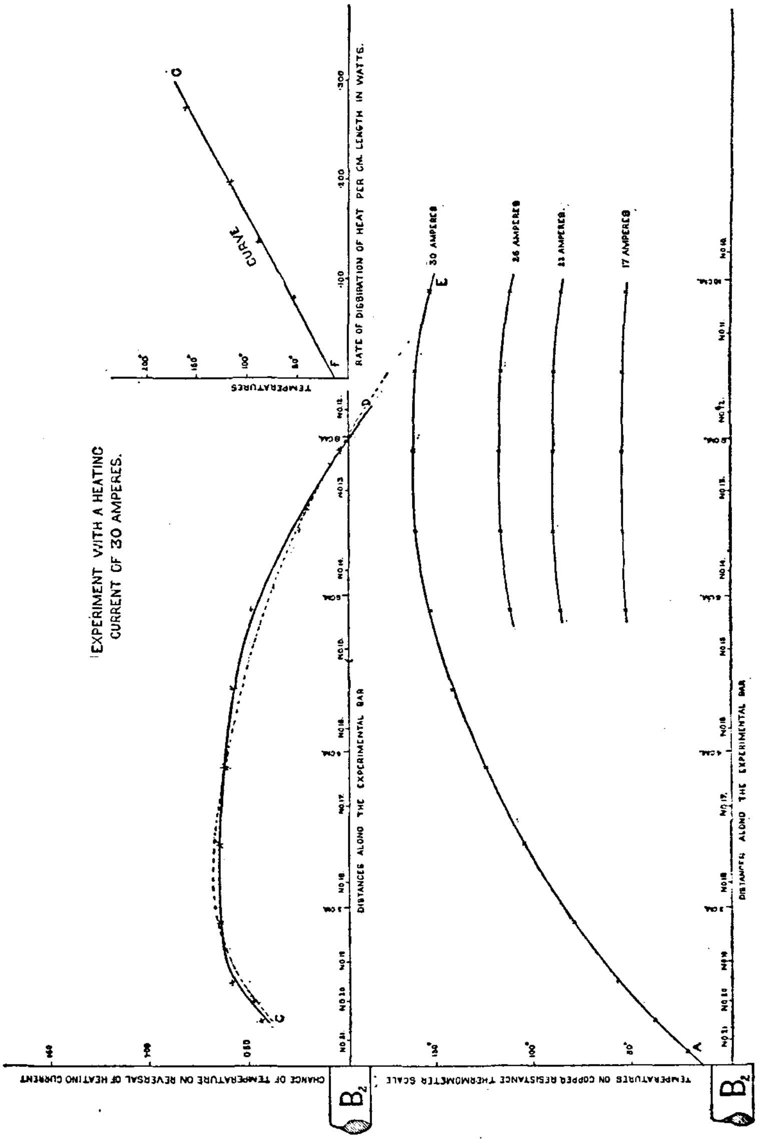
EXPERIMENT WITH A HEATING CURRENT OF 30 AMPERES.
CURVE
G
F
RATE OF DISSIPATION OF HEAT PER CM. LENGTH IN WATTS.
TEMPERATURES
30 AMPERES
26 AMPERES
23 AMPERES
17 AMPERES
E
D
C
A
DISTANCES ALONG THE EXPERIMENTAL BAR
CHANGE OF TEMPERATURE ON REVERSAL OF HEATING CURRENT
TEMPERATURES ON COPPER RESISTANCE THERMOMETER SCALE
B_2
B_2

FIGURE 5.

I. Section.	II. Potentiometer Turns representing Resistance.	III. Turns representing Change of Resistance.	IV. Calculated R_0.	V. Observed Resistance at 2 Amperes.	VI. Observed Resistance at 30 Amperes.	VII. Change of Resistance on Reversal.	VIII. Corresponding Change of Temperature on Reversal.	IX. Same by Smooth Curve.	X. Temperature.	XI. Rate of Dissipation of Heat.	XII. Change in Rate of Dissipation of Heat.
20 to 21	67.750	.108	.00010535	.00011162	.00012233	.000000195	0.439	0.413	38.2	.0216	.000233
19 to 20	51.160	.102	.00010751	.00011391	.00013333	.000000266	0.586	0.570	56.9	.0395	.000396
18 to 19	85.720	.174	.00021382	.00022654	.00028538	.000000579	0.642	0.642	79.3	.1224	.000991
17 to 18	81.090	.153	.00020832	.00022072	.00030031	.000000567	0.645	0.645	104.6	.1646	.001014
16 to 17	83.570	.141	.00021109	.00022365	.00032230	.000000543	0.610	0.616	124.8	.2050	.001012
15 to 16	81.690	.123	.00022977	.00024345	.00036718	.000000552	0.570	0.568	141.7	.2407	.000967
14 to 15	79.620	.099	.00021775	.00023071	.00035799	.000000445	0.485	0.454	152.6	.257	.000766
13 to 14	80.490	.047	.00021771	.00023066	.00036494	.000000213	0.232	0.272	160.2	.274	.000465
12 to 13	82.860	.008	.00022606	.00023951	.00038011	.000000037	0.039	. . . .	. . . .	. . . .	. . . .

The method of calculating the Thomson Effect from the above data has already been fully explained; so the principal quantities only are given in the table below:—

Section.	$k_{x_1}\left[\left(\frac{d\theta}{dx}\right)^1-\left(\frac{d\theta}{dx}\right)\right]$	$k_{13}\left[\left(\frac{d\theta}{dx}\right)-\left(\frac{d\theta}{dx}\right)^1\right]$	H^1-H	$\theta_{13}-\theta_{x_1}$	Mean Temperature of Section.	σ
20 to 13	.00696	−.00850	.005611	115.1	122	.00000628
19 to 13	.00302	−.00850	.005215	98.2	128	.00000509
18 to 13	.00000	−.00850	.004224	69.7	138	.00000483
17 to 13	−.00056	−.00850	.003210	47.1	146	.00000676

The *h* curve was determined by observations on the same section as in the experiments with 35 amperes. Referring to Fig. 5, *f g* is the curve obtained; it is quite straight and agrees with the *h* curve of Fig. 3 very well, as far as it goes. The bend in the latter depends principally on the observation at 35 amperes, which was, of course, not taken in this experiment.

The results of this experiment are of the same general character as in the experiment with 35 amperes. There is as before a decrease in the value of the Thomson Effect for higher temperatures, with the exception of the shortest section, that is, 17 to 13. This is due to the very flat top on the curve *c d*, Fig. 5. The curve *c d* in this experiment is not nearly so good as in the experiment with 35 amperes. This is unfortunate, as the whole calculation for the Thomson Effect with 30 amperes depends on this curve.

For this reason, another determination of the change of temperature, on reversal of the heating current, was made for the several sections, again using 30 amperes. More observations than before were taken, so that it is hoped the means are more accurate. Great care in every respect was taken. The resulting curve is shown dotted in Fig. 5. Its general form is more similar to the curve *c d* for 35 amperes, than the previous one, although the values of its ordinates do not differ greatly from it, the curves crossing each other at several points.

The principal quantities required for the calculation of the Thomson Effect as determined from this new curve are given below.

Section.	$k_{x_1}\left[\left(\frac{d\theta}{dx}\right)^1 - \left(\frac{d\theta}{dx}\right)\right]$	$k_{13}\left[\left(\frac{d\theta}{dx}\right) - \left(\frac{d\theta}{dx}\right)^1\right]$	$H^1 - H$
20 to 13	.00611	−.00840	.00548
19 to 13	.00506	−.00840	.00511
18 to 13	.00045	−.00840	.00410
17 to 13	−.00164	−.00840	.00305

Section.	$\theta_{13} - \theta_{x_1}$	Mean Temperature of Section.	σ
20 to 13	115°.1	122°	.00000597
19 to 13	98°.2	128°	.00000557
18 to 13	69°.7	138°	.00000496
17 to 13	47°.1	146°	.00000511

These results for the Thomson Effect seem to be considerably better than the first ones found with a heating current of 30 amperes. The value obtained for the shortest section and highest temperature is still a little larger than the one immediately preceding it; but it is a good deal smaller than the value found for the lowest temperature.

In order to see what effect a different value of the thermal conductivity would have on the character of the results as regards variation with temperature, the observations for the first experiment with 30 amperes have been worked through, using Stewart's value of the thermal conductivity. The modified results are given in column II. below. The original results, for the sake of comparison, of the first and second experiments are given in columns I. and III. respectively.

I. Values of σ from first experiments with 30 Amperes.	II. Values from I, modified by a change in value of Thermal Conductivity.	III. Values of σ from second experiments with 30 Amperes.	Mean Temperature of Section.
.00000628	.00000689	.00000597	122°
.00000509	.00000530	.00000557	128°
.00000483	.00000483	.00000496	138°
.00000676	.00000674	.00000511	146°

Comparison of the Experiments at 30 and 35 Amperes.

It is seen from the above results that the change made in the thermal conductivity has had the effect of increasing the diminution of the value of the Thomson Effect with a rise in temperature. The results of the two experiments with 30 amperes are not so consistent and regular as could be wished, yet it must be remembered that the reduction of the heating current from 35 to 30 amperes has probably lessened the accuracy of the work 50%. Taking from the experiment with 35 amperes the value of the Thomson Effect obtained with the largest number of sections, we have $\sigma = .00000608$ at 166° C. From the first experiment with 30 amperes we have $\sigma = .00000628$ at 122° C. These values agree fairly well, but exemplify the diminution of the Thomson Effect with a rise in temperature. From two experiments conducted on different parts of the experimental bar and with all the important quantities, such as temperature gradients etc., so different, it is satisfactory to obtain practically the same numerical value of the Thomson Effect and with one exception the same decided evidence of the diminution of the Thomson Effect with a rise of temperature.

Accuracy of the Resistance Measurements.

On page 371 it was pointed out that the decrease in the value of the Thomson Effect with rise of temperature could not be explained by even large errors in the assumed value of the thermal conductivity or in the form of the "*h* curve." Omitting these two sources of error, the balance of the work depends on the accuracy of the resistance measurements. The accurate measurement of such low resistances as 1 cm. lengths of no. 18 copper wire, presents considerable difficulty. However, an examination of the values obtained for the same sections of the bar at different times and under different temperature conditions will show that some success was attained.

Section.	April 24th, 1897.		May 5th, 1897.		Difference.
	I. Observed Resistance at 11°.9 C.	II. Resistance at 0° calculated from I.	I. Observed Resistance at 13°.9 C.	II. Resistance at 0° calculated from I.	
10 to 11	.00023128	.00022005	.00023304	.00021995	.00000010
11 to 12	.00023510	.00022369	.00023703	.00022372	.00000003
12 to 13	.00023724	.00022572	.00023951	.00022606	.00000034
13 to 14	.00022909	.00021797	.00023066	.00021771	.00000026
14 to 15	.00022854	.00021746	.00023071	.00021775	.00000029

These figures show a very satisfactory accuracy, the agreement in one case being as close as 1 part in 7,000, the worst agreement being 1 part in 700.

Comparison of the Results with those of Batelli.

Owing to the fact that Batelli made no experiments with copper, no direct comparison with his results can be made. He obtained for iron a value of .00001215 at a temperature of 108° and his values increased very rapidly with the temperature. This result is roughly twice as great as the value found above for copper. From the slope of the lines on the thermo-electric diagram given in J. J. Thomson's recent book on electricity and magnetism, it is seen that the Thomson Effect in iron should be about 5 times as great as in copper. Of course the determination of relative values in this way depends on making Tait's assumption that the Thomson Effect is directly proportional to the absolute temperature. If this assumption be true the determination of the Thomson Effect for different metals is very simple after its absolute value for one has been found. In the experiments described above, copper was chosen to be this particular one, because its properties suit the experimental conditions. As the results of the experiments are not in accord with Tait's assumption, it would not be consistent to deduce values of the Thomson Effect for other metals in the usual way. The further investigation of these very fundamental points is very desirable.

In closing, I wish to thank the authorities of the Jefferson Physical Laboratory for their kindness, and especially Dr. Hall for his advice and personal help with many difficult points.

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NOTE ON STOKES'S THEOREM IN CURVILINEAR CO-ORDINATES.

By Arthur Gordon Webster.

NOTE ON STOKES'S THEOREM IN CURVILINEAR CO-ORDINATES.

By Arthur Gordon Webster.

Presented April 13, 1898.

The expressions for the components of the curl of a vector point-function, when required in terms of orthogonal curvilinear co-ordinates, are usually obtained by direct transformation of their values in rectangular co-ordinates.

The proof of Stokes's Theorem, given in my Lectures on Electricity and Magnetism, due to Helmholtz, may be easily adapted to curvilinear co-ordinates so as to prove the theorem independently of rectangular co-ordinates.

Let P_1, P_2, P_3, be the projections of a vector P on the varying directions of the co-ordinate axes at any point. Let the projections on the same axes of the arc ds of a curve connecting the points A and B be ds_1, ds_2, ds_3. The theorem concerns the line integral of the resolved component of the vector along the given curve.

$$I = \int_A^B P \cos (P, ds)\, ds$$

$$= \int_A^B P_1\, ds_1 + P_2\, ds_2 + P_3\, ds_3.$$

But in terms of the curvilinear co-ordinates ρ_1, ρ_2, ρ_3, we have

$$ds_1 = \frac{d\rho_1}{h_1}, \quad ds_2 = \frac{d\rho_2}{h_2}, \quad ds_3 = \frac{d\rho_3}{h_3},$$

where

$$h_s^2 = \left(\frac{\delta \rho_s}{\delta x}\right)^2 + \left(\frac{\delta \rho_s}{\delta y}\right)^2 + \left(\frac{\delta \rho_s}{\delta z}\right)^2. \qquad s = 1, 2, 3.$$

Let us now make an infinitesmal transformation of the curve, so that the transformed curve shall lie on a given surface containing A and B, and shall itself pass through those points. Then the change in the integral due to changes in the co-ordinates $\delta \rho_1$, $\delta \rho_2$, $\delta \rho_3$, is,

$$\delta I = \delta \int \frac{P_1}{h_1} d\rho_1 + \frac{P_2}{h_2} d\rho_2 + \frac{P_3}{h_3} d\rho_3$$

$$= \int \delta \left(\frac{P_1}{h_1}\right) d\rho_1 + \delta \left(\frac{P_2}{h_2}\right) d\rho_2 + \delta \left(\frac{P_3}{h_3}\right) d\rho_3 + \frac{P_1}{h_1} d\,\delta\rho_1$$
$$+ \frac{P_2}{h_2} d\,\delta\rho_2 + \frac{P_3}{h_3} d\,\delta\rho_3.$$

The last three terms may be integrated by parts, giving

$$\int_A^B \frac{P_s}{h_s} d\,\delta\rho_s = \frac{P_s}{h_s}\,\delta\rho_s \Big/_A^B - \int_A^B \delta\rho_s\, d\left(\frac{P_s}{h_s}\right),$$

and the integrated part vanishing at the limits,

$$\delta I = \int \delta \left(\frac{P_1}{h_1}\right) d\rho_1 + \delta \left(\frac{P_2}{h_2}\right) d\rho_2 + \delta \left(\frac{P_3}{h_3}\right) d\rho_3 - \delta\rho_1\, d\left(\frac{P_1}{h_1}\right)$$
$$- \delta\rho_2\, d\left(\frac{P_2}{h_2}\right) - \delta\rho_3\, d\left(\frac{P_3}{h_3}\right).$$

Performing the operations denoted by δ and d, and collecting the terms which do not cancel,

$$\delta I = \int \Bigg[\left(\delta\rho_2\, d\rho_3 - \delta\rho_3\, d\rho_2\right) \left\{\frac{\delta}{\delta\rho_2}\left(\frac{P_3}{h_3}\right) - \frac{\delta}{\delta\rho_3}\left(\frac{P_2}{h_2}\right)\right\}$$
$$+ \left(\delta\rho_3\, d\rho_1 - \delta\rho_1\, d\rho_3\right) \left\{\frac{\delta}{\delta\rho_3}\left(\frac{P_1}{h_1}\right) - \frac{\delta}{\delta\rho_1}\left(\frac{P_3}{h_3}\right)\right\}$$
$$+ \left(\delta\rho_1\, d\rho_2 - \delta\rho_2\, d\rho_1\right) \left\{\frac{\delta}{\delta\rho_1}\left(\frac{P_2}{h_2}\right) - \frac{\delta}{\delta\rho_2}\left(\frac{P_1}{h_1}\right)\right\}.$$

Now the changes $\delta\rho_s$, $d\rho_s$, in the co-ordinates correspond to distances $\frac{\delta\rho_s}{h_s}$, $\frac{d\rho_s}{h_s}$, measured along the co-ordinate lines, and the determinant of these distances,

$$\frac{1}{h_2 h_3} \left(\delta\rho_2\, d\rho_3 - \delta\rho_3\, d\rho_2\right),$$

is equal to the area of the projection on the surface ρ_1 of the infinitesimal parallelogram swept over by the arc $d\,s$ during the transformation. Calling this area $d\,S$, and its normal n, we have

$$\frac{1}{h_2\,h_3}\,(\delta\,\rho_2\,d\,\rho_3 - \delta\,\rho_3\,d\,\rho_2) = \cos\,(n n_1)\;d\,S,$$

$$\delta\,\rho_2\,d\,\rho_3 - \delta\,\rho_3\,d\,\rho_2 = h_2\,h_3\cos\,(n n_1)\;d\,S.$$

Now, repeating the transformation so that the original curve 1 passes into a second given curve 2, the total change is represented by the surface integral over the surface lying between the curves,

$$\begin{aligned}\int\delta\,I = I_2 - I_1 = \iint\Bigg[& h_2\,h_3\left\{\frac{\delta}{\delta\,\rho_2}\left(\frac{P_3}{h_3}\right) - \frac{\delta}{\delta\,\rho_3}\left(\frac{P_2}{h_2}\right)\right\}\cos\,(n n_1)\\ & + h_3\,h_1\left\{\frac{\delta}{\delta\,\rho_3}\left(\frac{P_1}{h_1}\right) - \frac{\delta}{\delta\,\rho_1}\left(\frac{P_3}{h_3}\right)\right\}\cos\,(n n_2)\\ & + h_1\,h_2\left\{\frac{\delta}{\delta\,\rho_1}\left(\frac{P_2}{h_2}\right) - \frac{\delta}{\delta\,\rho_2}\left(\frac{P_1}{h_1}\right)\right\}\cos\,(n n_3)\Bigg]\,d\,S.\end{aligned}$$

But the difference of the line integrals $I_2 - I_1$ is the line integral around the closed contour 12, so that we have the line integral of the tangential component of the vector P around the closed contour proved equal to the surface integral over a surface bounded by the contour of the normal component of a vector Ω whose components are

$$\omega_1 = h_2\,h_3\left\{\frac{\delta}{\delta\,\rho_2}\left(\frac{P_3}{h_3}\right) - \frac{\delta}{\delta\,\rho_3}\left(\frac{P_2}{h_2}\right)\right\}$$

$$\omega_2 = h_3\,h_1\left\{\frac{\delta}{\delta\,\rho_3}\left(\frac{P_1}{h_1}\right) - \frac{\delta}{\delta\,\rho_1}\left(\frac{P_3}{h_3}\right)\right\}$$

$$\omega_3 = h_1\,h_2\left\{\frac{\delta}{\delta\,\rho_1}\left(\frac{P_2}{h_2}\right) - \frac{\delta}{\delta\,\rho_2}\left(\frac{P_1}{h_1}\right)\right\}.$$

The vector Ω is called the curl of P.

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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE, E. L. MARK, DIRECTOR, No. XCII.

A CONTRIBUTION TO THE STUDY OF INDIVIDUAL VARIATION IN THE WINGS OF LEPIDOPTERA.

By William L. W. Field.

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By William L. W. Field.

Presented by E. L. Mark, April 13, 1898.

I. Statement of the Problems.

This paper gives the results of an attempt to find, in a particular species, answers to the following questions: —

1. Is a part, developed in any given species in an extraordinary manner as compared with the development of the corresponding part in other allied species, more variable than parts which exhibit less specific peculiarity?

2. Which sex is the more variable?

The first question is raised to test, by quantitative methods, the law of variation enunciated by Darwin (Origin of Species, 6th edition, §§ 220, 221). It is unnecessary to argue the importance of tests of this kind. From data offered by others we may obtain quantitative expressions of certain cases. Thus, while in nearly all groups of Mammals except the sloths the number of cervical vertebræ is 7, it is a familiar fact that in this aberrant group the number varies from 6 to 10. Bateson ('94) gives the following data obtained from fifty-seven individuals belonging to the genus Bradypus: —

No. of Cervical Vertebræ	8	9	10
No. of Cases	6	46	5

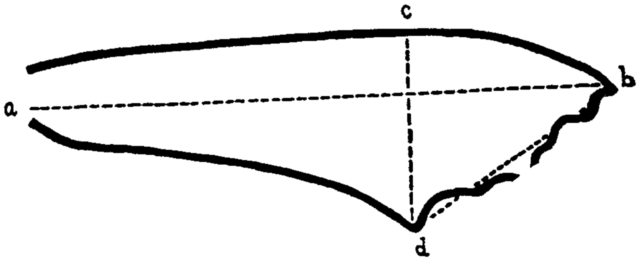
Mean, 8.98+. Average Deviation from Mean, 0.21—.

With regard to the characteristic under consideration, the Average Deviation for other Mammals will be 0.00+. The comparison of these two Average Deviations gives us a measure of the greater variability of the group with the exceptional structure. Other contributions to this law from other groups of animals are needed.

The second question bears upon the significance of sexual dimorphism. The quantitative studies of Davenport and Bullard ('96) upon the glands in the fore legs of pigs show the variability of the males to exceed that of the females by 2.5% ; while, on the contrary, Pearson ('97) shows that women are in general slightly more variable than men, — exhibiting the greater degree of variability in eleven out of a total of seventeen characters under consideration.

II. METHOD.

The species upon which I have worked is the moth *Thyreus abbotii* Swainson, one of the common Sphingidæ of Eastern North America. It differs from its allies most notably in that the outer margins of the primaries are excessively irregular and extraordinarily long, as compared with other dimensions of the wings. I have tried to find an answer to the question, Is this extraordinary outer margin more variable than other more ordinary characters of the same wing?



THYREUS ABBOTII SWAINSON: RIGHT PRIMARY.

(*Enlarged Shadow.*)

FIGURE 1.

For measurement and comparison with the margin (1), I selected the following three dimensions for measurement: —

(2) The length, from insertion to apex (*a–b* in Figure 1);

(3) The greatest breadth, — the perpendicular distance of the posterior protuberance of the outer third of the wing from the costa (*c–d*) ;

(4) The length of an imaginary straight line drawn between the extremities of the sinuous margin, — that is, from apex to posterior protuberance (*b–d*).

The three dimensions defined above were measured with a pair of sharp-pointed dividers with screw adjustment, and a scale graduated in millimetres. To eliminate error, precautions were taken which will shortly be described.

The measurement of the margin required special apparatus; and after a number of experiments I succeeded in constructing an inexpensive and efficient projecting instrument, as follows. A vertical wooden post, about eight inches high, was firmly fixed to one end of a solid base-block. On the top of the post was placed a binding-screw, which held a horizontal brass rod, to the extremity of which was fastened a miniature incandescent electric lamp of two candle-power. The electrical connections were formed respectively by the carrying-rod and a flexible spiral of fine wire, the latter also leading to a binding-screw. A one-point switch, situated upon the base-block, served to open and close the circuit. To the lower portion of the post, and projecting horizontally beyond the end of the base-block, was fixed an arm carrying still another binding-screw, holding a vertical steel rod, in such a way as to afford a considerable range of adjustment up and down. To the upper extremity of this rod was fastened a firm "stage" of cork, in which the pin bearing a specimen might be inserted. A graduated scale upon the post permitted an approximate determination of adjustment in height.

The function of this instrument was to project an enlarged shadow of the wing upon a sheet of paper placed upon the table, so that the outline might be traced with a pencil. When connected with three cells of a "Samson" open-circuit battery, in a darkened room, it did its work admirably. The shadow produced was sharp and clear, and could be drawn quite as accurately as the image formed by an Abbé camera.

Of course it was not easy to gauge the enlargement (and consequent distortion) of the image accurately; but this was unneccessary. The error being almost exactly the same for the sinuous line and its "chord," (as I have termed the straight line *b–d*, Figure 1, drawn between its extremities,) it was only necessary to find the ratio between the two, — the actual length of the "chord" being afterward measured directly from the specimen, with the aid of the dividers already referred to. The projected "chord" was measured with a metric ruler, and the sinuous line with an "Entfernungsmesser," or map-measurer.*

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* The map-measurer is an instrument provided with a small wheel, which is made to roll along the line to be measured, and a recording dial, registering in centimetres the distance covered. Instruments of this sort are small and rather cheap, and may usually be obtained from dealers in draughtsmen's supplies.

In reading the adjustment of the dividers, the distance was laid off four times along a ruled line, and the result was divided by four. This served to diminish errors in the use of the scale. The dividers were always returned to the starting point as a test for change of adjustment, but no change ever appeared. The error introduced in this process was probably less than one per cent.

The "Entfernungsmesser," as I have said, registers in centimetres. To obtain an accurate reading, it was run over each line a number of times (sometimes fifteen or twenty, if error were suspected), and the reading for ten trips was taken direct, with the substitution of millimetres for the centimetres of the reading. This method was laborious, but accurate. By actual test the average error was found to be less than one per cent.

III. Results.

In the following tables, AD stands for Average Deviation of the measurements from the mean of all; CV for the Coefficient of Variation, which is the average deviation divided by the mean.

	Wing Length (Fig. 1, *a–b*).	Wing Breadth (Fig. 1, *c–d*).	Chord (Fig. 1, *b–d*).	Margin.
	mm.	mm.	mm.	mm.
Total of measurements of 31 males	929.6	333.2	450.3	529.7
Mean	29.9	10.7	14.5	17.1
Total of deviations	20.3	10.1	14.0	24.2
AD (sexual)	0.654	0.322	0.451	0.780
CV (sexual)	0.022	0.030	0.031	0.046
Total of measurements of 19 females	598.2	213.6	281.2	340.1
Mean	31.5	11.2	14.8	17.9
Total of deviations	13.9	7.6	11.0	14.4
AD (sexual)	0.731	0.400	0.578	0.754
CV (sexual)	0.023	0.036	0.039	0.042
Total of measurements of 50 specimens, both sexes	1527.8	546.8	731.5	869.8
Mean	30.5	10.9	14.6	17.4
Total of deviations	45.3	21.0	26.1	36.0
AD of species	0.906	0.420	0.522	0.720
CV of species	0.030	0.039	0.036	0.041
Curves of distribution of individual measurements	Fig. 2	Fig. 3	Fig. 4	Fig. 5

The results may be summarized thus: —

	31 Males.		19 Females.		50 Both Sexes.	
	AD	CV	AD	CV	AD	CV
Wing length	.654	.022	.731	.023	.906	.030
Wing breadth	.322	.030	.400	.036	.420	.039
Length of chord	.451	031	.578	.039	.522	.036
Length of sinuous margin . . .	.780	.046	.754	.042	.720	.041

From this table it appears that the length of the sinuous margin has a greater Coefficient of Variability than any of the other dimensions measured, being

In the male	48%	greater than	CV	of chord.
In the female	8%	"	"	"
In both sexes taken together	14%	"	"	"

Comparing the Average Deviations of the two dimensions, we find a still greater proportional difference.

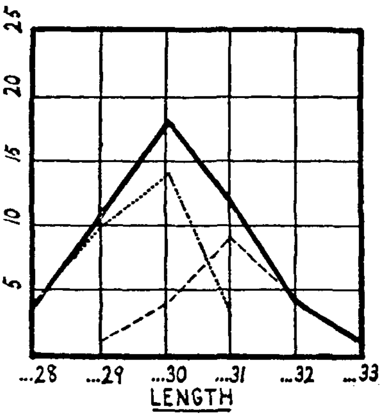

FIGURE 2.

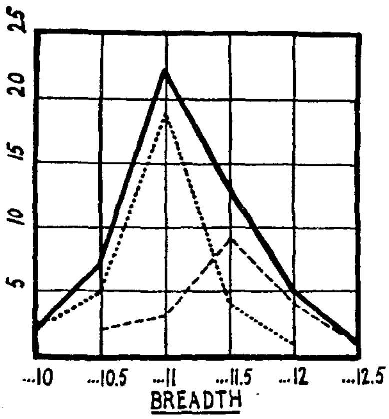

FIGURE 3.

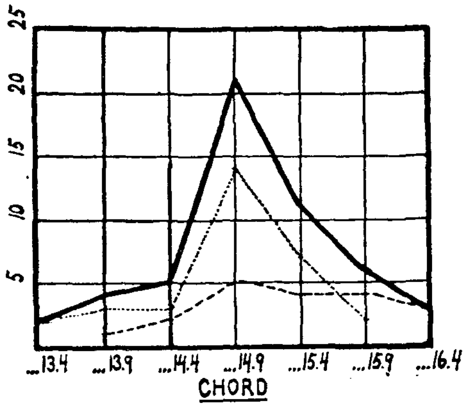

FIGURE 4.

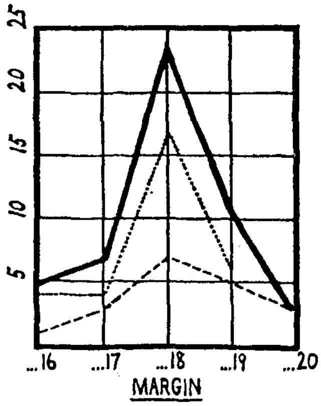

FIGURE 5.

DIAGRAMS ILLUSTRATING INDIVIDUAL VARIATION IN THYREUS ABBOTII.

Numbers of specimens plotted as ordinates; measurements (in millimetres) as abscissæ. The numbers appended to the ordinates indicate the maximum measurements in the respective groups.

———— Both Sexes; ·········· Males; ---------- Females.

Comparing the results obtained from the males with those from the females, we find the greater variability in the latter sex, except in the case of the sinuous margin. This does not accord with the generally accepted theory of the variability of the sexes, but if there were sufficient statistical data it would probably appear as a rather common phenomenon among the Lepidoptera; for dimorphic and trimorphic females are found in very many species.

IV. CONCLUSIONS.

In the moth *Thyreus abbotii*, the most aberrant dimension of the fore wing is likewise the most variable. This accords with Darwin's law.

The females show, in general, a greater degree of variability than the males; but in the one markedly aberrant feature under discussion, their variability is less than that of the males. I submit the following hypothesis to explain the smaller variability of the sinuous margin in the females. The fact that the wing broadens so greatly toward the tip, and is provided with an irregular edge, suggests that this form of margin may be of advantage in rendering the insect less distinctly visible when its wings are in rapid motion. This idea is upheld by the fact that a related species, *Amphion nessus* Cramer, has the same effect produced in color where irregularity of form is wanting. If this hypothesis be admitted, then we must look for a better development of the protective feature in the female than in the male, since the female, when burdened with eggs, cannot fly as rapidly as her mate. The sinuous margin being of less importance, comparatively, for the male, we can understand its greater variability in that sex, where it is less rigidly selected.

The work which I have here described was performed in connection with my studies under Dr. Charles B. Davenport, at Harvard University, in 1896–97. I am indebted to him for valuable suggestions and advice.

BIBLIOGRAPHY.

Bateson, W.
'94. Materials for the Study of Variation. London.

Davenport, C. B., and Bullard, C.
'96. Studies in Morphogenesis, VI. A Contribution to the Quantitative Study of Correlated Variation and the Comparative Variability of the Sexes. Proc. Amer. Acad. Arts and Sci., Vol. XXXII. pp. 87–97.

Pearson, K.
'97. The Chances of Death, and other Studies in Evolution. Vol. I. Chapter VIII. — Variation in Man and Woman. London.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE CAUSE OF THE RETENTION AND RELEASE OF GASES OCCLUDED BY THE OXIDES OF METALS.

By Theodore W. Richards.

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ON THE CAUSE OF THE RETENTION AND RELEASE OF GASES OCCLUDED BY THE OXIDES OF METALS.

By Theodore William Richards.

Presented March 9, 1898.

In a recent critical discussion of Stas's work upon the atomic weight of carbon, Dr. Alexander Scott* of London had occasion to repeat some observations made at Harvard several years ago.† According to these observations, cupric oxide made from cupric nitrate had been found usually to contain several times its volume of occluded gases, chiefly nitrogen, and moreover it was shown that this gas resulted from the decomposition of minute traces of residual nitrate confined in the inmost recesses of the masses of oxide. Dr. Scott, however, could not find as much as one tenth of this amount of gas in his material. Since he was unable to explain the apparent discrepancy, it is one of the objects of the present paper to shed a clearer light upon the subject.

The essential point which escaped Dr. Scott's notice is this: the temperature of ignition is the most important condition determining the amount of the occluded gases. When the temperature is very high, nearly all of the imprisoned impurity is set free. To quote Dr. Scott's words, his oxide was exposed "for varying times to a full red heat in a muffle heated with gas." It is well known that at a temperature of about 1000° cupric oxide melts, with a very considerable loss of oxygen. It is obvious, then, that temperatures in this neighborhood are quite out of the question when the atomic weight of copper is concerned; hence, among the many experiments made by me in 1891, only three dealt with material which had been heated above 700°. The evidence of these three experiments (Nos. 59, 81, and 95), is unanimous in showing that most of the occluded impurity is set free at bright redness, and the first two of them agree quantitatively with the results of Dr. Scott.

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* Journ. Chem. Soc. Trans., LXXI. 559. (1897.)

† These Proceedings, XXVI. 281; Z. Anorg. Chem., I. 196.

Although it is thus evident that the English and American results are in no way inconsistent, I decided to repeat a part of the work, in order to obtain a more certain estimate of the various temperatures corresponding to the varying conditions of the cupric oxide. In my previous paper the higher degrees had been merely guessed, for they were not directly concerned in the point then under consideration.

The usual modes of determining high temperatures — the calorimeter, the air-thermometer, the bolometer, the meldometer, the platinum-iridium thermopile, etc. — are somewhat troublesome to use for a brief series of experiments of the present kind, so that it seemed best to determine the several temperatures approximately by finding for each temperature two substances, whose melting points were respectively above and below the point in question. For instance, an intensity of heat which would melt pure argentic bromide but not pure argentic chloride must be between 427° and 451°, a grade of accuracy more than sufficient for the present purpose. This method of determining the temperature has the great advantage of providing an approximate self-registering thermometer, occupying very small space and needing no connection with the outside air. The usefulness of the method obviously depends upon the number of substances easily obtained in a pure state, whose melting points are accurately known. For such knowledge of high melting points we depend mainly upon four researches. — those of Carnelley,* Le Chatelier,† Meyer, Riddle, and Lamb,‡ and Ramsay and Eumorfopoulos.§ Unfortunately the results of these four investigations do not always agree, their disagreement affording evidence of the great difficulty of measuring accurately high temperatures. At first sight the fact of the existence of such discrepancy might deter one from adopting this standard of reference, but further consideration leads to exactly the opposite conclusion. The melting points of pure salts must be an unchangeable standard, and the uncertainty of our knowledge regarding them must be largely due to experimental difficulties in the thermometric manipulation. These difficulties, if so serious in researches where everything was favorable to accuracy, must be largely augmented in a research like the present one, in which the temperature could not be made the sole issue of the experiment. Hence the melting point of a pure salt is the safest possible standard. The following table gives in parallel columns the salts chosen for the present scale of temperature, with the results of the four investigations, and the values of the melting points selected as the most probable.

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* Carnelley, Journ. Chem. Soc., XXIX. 489, XXXIII. 273. (1876 and 1878.)

† Le Chatelier, Bull. Soc. Chem., XLVII. 300. (1887.)

‡ V. Meyer, Riddle, and Lamb, Berichte der Deutsch. chem. Gesell., XXVII. 3129. (1895.)

§ Ramsay and Eumorfopoulos, Phil. Mag., (5.), XLI. 360. (1896)

TEMPERATURE SCALE.

	Carnelley Calorimeter.	Le Chatelier Thermopile.	Meyer Air Therm.	Ramsay Meldometer.	Value Selected.
Potassic nitrate	339	—	—	339	339
AgI, 2 AgBr, 2 AgCl	383	—	—	—	383
Argentic bromide	427	—	—	426	427
Argentic chloride	451	—	—	460	451
Plumbic chloride	498	—	—	447	498
Argentic iodide	527	—	—	556	527
Sodic biborate	561	—	—	—	561
Lithic chloride	598	—	—	491	598
Thallous sulphate	632	—	—	—	632
Strontic nitrate	645	—	—	570	645 (?)
Potassic bromide	699	—	722	733	720
Potassic chloride	734	740	800	762	760
Sodic chloride	772	775	815.4	792	790
Sodic carbonate	814	810	849	851	830
Strontic chloride	825	840	832	796	835 (?)
Sodic sulphate	861	867	863	884	865
Baric chloride	860	—	921	844	920 (?)
Potassic sulphate	—	1045	1078	1052	1060

The most serious discrepancies are to be noticed in the cases of potassic and sodic chlorides, where the respective averages have been chosen as the most probable values. These averages are almost identical with the figures obtained by Ramsay and Eumorfopoulos. On the other hand, Joly's meldometer, used by these investigators, seems to have been much less satisfactory at lower temperatures; for their melting points of plumbic chloride and lithic chloride are widely different from Carnelley's. Repeated qualitative experiments have convinced me that plumbic chloride is less easy to melt than argentic chloride, and lithic chloride less easy to melt than argentic iodide; therefore Carnelley's calorimetric results have been adopted here as the more accurate. Strontic nitrate, and strontic and baric chloride all begin to decompose in the air at or near their melting points; undoubtedly this fact is responsible for the very low results obtained by Ramsay and Eumorfopoulos in these cases. Obviously such salts cannot be relied upon as trustworthy thermometers, unless one takes the precautions observed by Meyer, Riddle, and Lamb in their work with the air thermometer. One is reminded of the interesting work of Hill upon changeable organic melting points.* The other substances in the list are sufficiently stable, and are easily obtained in a pure state. In the light of Le Chatelier's complete confirmation of Carnelley's results by means of the pyrometric thermopile, it is odd that the lamented Victor Meyer accorded Carnelley so little credit as he has done.

It is needless to state that pains was taken to eliminate impurities from these substances by recrystallization or other suitable means, and to dry the salts thoroughly, in the work which follows. If the temperature was below 800°, the dry coarsely powdered substances were contained in small melting-tubes of the hardest Jena glass, sealed while hot at both ends, and sometimes provided with a small platinum sinker to show whether or not the salt had liquefied. If, on the other hand, the height of the temperature excluded glass, the substances were contained in small cups beaten into stout strips of platinum foil. The small amount of impurity taken from the glass tubes in which some of the substances were melted could hardly have had much effect on the melting points until after a considerable mass of the substances had been melted; but then their mission had been fulfilled.

The table above might well be amplified to cover a wider range, as well as smaller differences of temperature, but such an amplification would constitute a research of some magnitude in itself. For present purposes the above will suffice.

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* H. B. Hill, These Proceedings, XXIII. 219.

Two forms of apparatus were used for determining the amount and the composition of the occluded gases. The first was identical in every respect with the most convenient of the three forms described in the original paper.* It consists of several bulbs blown in the bend of a glass tube bent at a right angle. One arm of the tube is temporarily closed by a stopcock, (not shown in the cut in the original paper, although mentioned in the letterpress,) and in this arm the gas, evolved in the bulbs by the solution of the cupric oxide in acid, is collected and measured over boiled water. When necessary the gas may be readily removed through the stopcock at the end of the arm; if a gas burette is attached here, of course the gas may be analyzed at once without further trouble.

For most of the experiments, however, Scott's modification of another of the original forms † was used. The mode of operating this apparatus was essentially similar to the method just described, although the bent tubes and bulbs are replaced by a small flask and funnel-tube. Scott's addition of a side tube to remove the displaced water distinctly increases the convenience and accuracy of the contrivance. For the details his paper should be consulted.

The two pieces of apparatus give identical results, which cannot be far from the truth. If at all in error the amount of gas collected must be too small rather than too large, for both oxygen and nitrogen are slightly soluble in water. This consideration was verified by fusing a specimen of oxide (another portion of which had been repeatedly analyzed in the usual fashion) with carefully prepared acid potassic sulphate in a Sprengel vacuum. The amount of gas evolved by this treatment was slightly greater, but only slightly greater than the amount obtained by the usual method, and its composition was essentially identical with that of the gas collected over boiled water. Since the question is one of relation, rather than of absolute values, the method involving the use of aqueous solutions was adopted because of its far greater ease of execution. Pains was taken to have the conditions of the solution of the oxide always as nearly as possible the same, so that the results should be strictly comparable with one another.

The first object of the present paper is to show more clearly the relation between the amount of gas retained by the oxide and the temperature used in its ignition. The material employed in these experiments was prepared by dissolving pure copper wire or electrolytic copper in pure nitric acid, and converting by heat the recrystallized cupricnitrate into basic nitrate and finally into oxide.* Platinum vessels were used throughout, whenever heating was necessary, excepting that one or two of the first ignitions were conducted in a porcelain boat. Three preparations of the oxide were made ; one by the rapid decomposition of the nitrate, another by more gradual application of heat, and a third by the very slow action of a temperature just barely sufficient to effect the desired change. This temperature had been previously found by a special experiment to be about 275°, if the products of the decomposition remain in contact with the cupric oxide. The first of these preparations was the most coherent, and was capable of retaining the most gas ; the second was less coherent and retained less gas, and the last was the most powdery and retained even less gas. Thus it is manifest that the physical condition of the solid is a factor in the question.

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* These Proceedings, XXVI. 284. (1891.)

† These Proceedings, XXVI. 285, middle of page.

These specimens of the oxide of copper were subsequently ignited at varying temperatures for varying lengths of time in two different forms of furnace. For the first series a large tube or small muffle of Berlin porcelain capable of being heated to 1200° or more in a Fletcher furnace was used, but since it was found difficult to maintain the tube at a constant temperature throughout, this arrangement was later abandoned. All the subsequent ignitions were performed in a double crucible arranged in the manner shown in the diagram, the low platinum crucible or capsule used to contain the cupric oxide, being protected from radiation and convection by a number of superimposed crucible lids. The outer glazed porcelain crucible and the layers of asbestos board covering the draught holes united in excluding the products of combustion of the illuminating gas from the contents of the inner capsule. By means of this furnace, fed with a constant gas supply burning from a fourfold Bunsen burner, a surprisingly constant and uniform temperature may be maintained for an indefinite length of time.

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* It is interesting to note that the hydrate of cupric nitrate, which crystallizes from hot solutions, probably has the formula $3\,Cu(NO_3)_2 \cdot 8\,H_2O$ (analogous to cadmic sulphate), not $Cu(NO_3)_2 \cdot 3\,H_2O$ (Graham), as is usually supposed. Following are the analyses of three separate preparations, dried over moist potash (which does not dehydrate the crystals at ordinary temperatures) proving this point.

(1) 0.1739 gram of crystals yielded 0.0471 gram of copper = 27.08 per cent.
(2) 0.6310 " " " 0.1705 " " = 27.01 "
(3) 1.2897 " " " 0.3448 " " = 26.73 "
Average = 26.94 "

Theoretical value for $Cu(NO_3)_2 \cdot 3\,H_2O$ = 26.20 per cent of copper.
" " $3\,Cu(NO_3)_2 \cdot 8\,H_2O$ = 26.98 " "
" " $2\,Cu(NO_3)_2 \cdot 5\,H_2O$ = 27.35 " "

The crystals analyzed in No. 3 above were large and undoubtedly contained included mother liquor. Whether or not other hydrates exist, and what the transition temperatures may be, I did not take the trouble to discover. Much of our present data regarding water of crystallization has been rounded off in the manner indicated above. Undoubtedly many more such irregular ratios as 3 : 8 really exist than we are prepared at present to believe.

In the following table are given the new series of results showing the relation of the total volume of gas retained to the temperature used in the ignition of the cupric oxide. The gas volumes are reduced to 0° and 760 mm. pressure, the reduction having been made by means of a Winkler-Lunge corrector arranged to give directly the exact volume of a mass of moist air which would measure a hundred cubic centimeters when dry and under standard conditions.

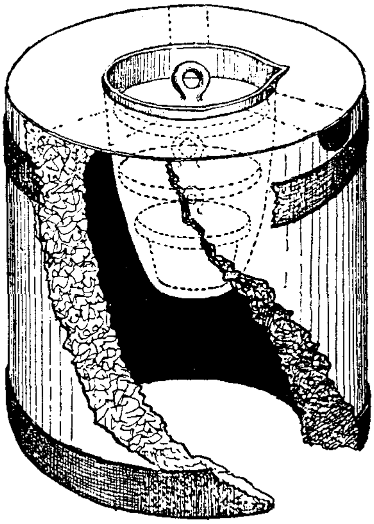

FIGURE 1.

THE EFFECT OF TEMPERATURE ON THE TOTAL AMOUNT OF GAS OCCLUDED BY CUPRIC OXIDE.

First Series: First Preparation of Cupric Oxide.

(1)	1 gram CuO, heated 1 hour at 300° ±,* gave	0.18 c.c. gas.
(2)	" " " "	0.19 "
(3)	" " " "	0.21 "
	Average	0.19 c.c. gas.
(4)	1 gram CuO, heated 4 hours at 500° ±,† gave	0.69 c.c. gas.
(5)	" " " "	0.72 "
	Average	0.70 c.c. gas.

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* Mercury thermometer.

† Plumbic chloride just fused; argentic iodide remained solid.

(6)	1 gram CuO, heated 1 hour at 830° ±,[*] gave	0.68 c.c. gas.
(7)	“ “ “ “	0.69 “
(8)	“ “ “ “	0.68 “
	Average	0.68 c.c. gas.
(9)	1 gram CuO, heated ½ hour at 870° ±,[†] gave	0.55 c.c. gas.
(10)	1 gram CuO, heated ½ hour at 900° ±,[‡] gave	0.08 “
(11)	1 gram CuO, heated ½ hour at 950° ±,[§] gave	0.05 c.c. gas.
(12)	“ “ “ “	0.04 “
	Average	0.05 c.c. gas.
(13)	1 gram CuO, heated ½ hour at 1100° ±,[‖] gave	0.01 (?) c.c. gas.

Second Series: Second Preparation of Cupric Oxide.

(14)	1 gram CuO, heated 4 hours at 280° ±,[¶] gave	0.04 c.c. gas.
(15)	1 gram CuO, heated 1 hour at 290° ±,[¶] gave	0.12 c.c. gas.
(16)	1 gram CuO, heated 5 hours at 630°,[**] gave	0.54 c.c. gas.
(17)	1 gram CuO, heated 3 hours at 830°,[††] gave	0.57 c.c. gas.
(18)	“ “ “ “	0.59 “
(19)	1 gram CuO, heated 5 hours at 830°, gave	0.57 “
	Average	0.58 c.c. gas.
(20)	1 gram CuO, heated 20 minutes at 870° ±,[††] gave	0.42 c.c. gas.
(21)	“ 150 “ “	0.23 “
(22)	“ “ “ “	0.14 “
(23)	1 gram CuO, heated 2 hours at 950° ±,[††] gave	0.04 c.c. gas.
(24)	“ “ “ “	0.07 “
(25)	“ “ “ “	0.04 “
	Average	0.05 c.c. gas.

These two series of experiments, qualitatively and quantitatively similar to those carried out in 1891, lead to the following conclusions, which are copied verbatim from the paper on the atomic weight of copper: —

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[*] Sodic chloride easily fused; strontic chloride just fused; sodic sulphate remained solid.

[†] Sodic sulphate just fused.

[‡] Sodic sulphate easily fused; higher than last.

[§] Baric chloride easily fused; potassic sulphate remained solid.

[‖] Potassic sulphate fused, as well as the cupric oxide itself.

[¶] Mercury thermometer.

[**] Thallous sulphate just melted.

[††] See foot-notes to preceding series for criteria regarding temperatures 830°, 870°, and 950°.

"First, *that cupric oxide prepared by the ignition of the oxynitrate after Hampe's method contained between four and five times its volume of occluded gas.*

"Second, *that ignition of the oxide at very bright redness was capable of expelling a portion of this gas. The temperature required was nevertheless considerably above that which Hampe apparently employed.*"

The recent experiments add to these conclusions only greater definiteness. It is now clear that nearly all the gas is retained until a temperature of slightly over 860° is reached, when more than nine tenths of it is rapidly set free. Somewhat above this point the cupric oxide is itself partly decomposed; and in the neighborhood of 1000° the mixture of cupric and cuprous oxides fuses first into a mass resembling scoria, and then into a limpid fluid. It is evident that Scott must have used in his muffle a temperature somewhere between 850° and 1000°; for he found on the average 0.055 c. c. of gas per gram of cupric oxide, while my results obtained by means of temperatures in this neighborhood average 0.05 c. c. Moreover, some of his material was slightly reduced, but apparently none of it was melted.

It was clearly shown in the previous papers that the low results given by material ignited at temperatures below 450° are due to the presence of undecomposed cupric nitrate, which by its decomposition at higher temperatures yields the gas forming the subject of the present discussion.

The fact that prolonged ignition does not affect the amount of gas occluded may be inferred from the experiments just recorded; but in order to obtain more definite information on this influence of time, a third series of experiments was made.

The Effect of Time of Ignition on the Total Amount of Gas occluded by Cupric Oxide.

Temperature: The Fusing Point of Thallous Sulphate, about 640°.

(26)	1 gram of CuO, after ignition for 10 minutes, gave	0.56 c.c. gas.
(27)	" " "	0.57 "
(28)	" " "	0.53 "
	Average	0.55 c.c. gas.
(29)	1 gram of CuO, after ignition for 5 hours, gave	0.56 c.c. gas.
(30)	" " "	0.59 "
	Average	0.57 c.c. gas.
(31)	1 gram of CuO, after ignition for 20 hours, gave	0.56 c.c. gas.
(32)	" " "	0.59 "
	Average	0.57 c.c. gas.

A portion of the last specimen, which had been heated for twenty hours, was further ignited for five hours at about the fusing point of common salt (about 800°). Upon solution in acid this portion yielded the same amount, 0.59 c. c. of gas. Thus another of the conclusions arrived at in 1892 is confirmed: —

"Third, *that beyond a certain limit the time of ignition makes no important difference.*"

This is true, however, only below 850°. Experiments 20 to 22 show that when the imprisoned gas has once begun to be set free, at temperatures above 850°, the time is an essential factor; and that when sufficient time has been allowed, the expulsion of the gas is almost complete. Scott examined only cupric oxide from which he had thus expelled the gas.

In this connection it is interesting to note that Morse and Arbuckle * have recently verified, with apparatus far more elaborate and exact than ours, the results of Rogers and myself concerning the amount of gas occluded by the oxide of zinc.† Considering the fact that the manner of preparation of the substance undoubtedly affects the amount of gas retained, the closeness of the agreement is surprising. Only one of their conclusions is different from ours: in their opinion, there is no reason to believe that the temperature of ignition of the oxide has any effect on the composition of the occluded gas, while in our experiments the imprisoned oxygen decreased with increasing temperature. The basis of their reasoning is the supposition that the total amount of gas retained is dependent solely upon the temperature; using this total amount as a thermometer, they point out the fact that the smaller amounts of gas obtained in their experiments did not always contain the smaller amounts of oxygen; and hence they conclude that the temperature is not an essential determining cause of the composition of the mixture. In a letter answering some questions about the matter, Professor Morse kindly writes "We made every effort to secure constant temperatures for our oxide, giving the closest attention, to that end, to every detail of the firing of the furnace, the fuel, the location of the crucibles," etc. Since this is the case, and I cannot doubt the essential success of their efforts, it seems to me that their results have but little bearing upon the effect of *varying* temperatures on the oxide. The fact that their mixture of gases was by no means constant in composition is better explained by the supposition that some other cause besides the temperature influences the relation of the volumes of oxygen and nitrogen retained, or else that the total amount of the enclosed gases is not a safe measure of the temperature. It will be shown that both of these inferences are correct, and hence that the logic of Morse and Arbuckle's point, correct in itself but unsafe in its premises, falls to the ground.

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* Amer. Chem. Journal, XX. 195.

† These Proceedings, XXVIII. 200.

A careful study of all the data, Morse and Arbuckle's as well as ours, convinced me that, while the two gases must be evolved together, they behave subsequently in quite a different fashion. It is apparent immediately that the oxygen must escape at first much faster than the nitrogen, for the ratio of the two volumes in the nitric anhydride set free must be originally 5 : 2, while the average of Morse and Arbuckle's result showed that less than a fifth of the finally retained mixture consisted of oxygen. Part of the loss might be due to the preliminary formation of lower oxides, and to unequal diffusion, but this cannot account for so great a loss of oxygen. Even nitrous oxide should yield upon decomposition a mixture one third of the volume of which must consist of oxygen; and the fractional diffusion of this mechanically enclosed mixture should allow the lighter of its two constituents, nitrogen, to escape the more quickly of the two; hence the mixture should contain never less than thirty-three per cent of oxygen. The same anomaly is even more manifest in the case of cupric oxide, for from this substance nearly all the oxygen soon escapes even at comparatively low temperatures.

Why then does the oxygen escape the more easily of the two gases? This question introduces us at once to the second section of the paper, which deals with the composition of the occluded gases.

The first step toward answering the question is a certain determination of the facts, which have been doubted by Morse and Arbuckle. The three conditions which would be most likely to affect the amount and composition of the gaseous mixture are the temperature of ignition, the time of ignition, and the compactness of the solid material. In order to test the effect of these possible modifying causes experimentally, several series of analyses were made, both with zincic and with cupric oxide.

The zincic oxide was made by heating pure zincic nitrate for a long time at 280°. It was more compact than the cupric oxide, and undoubtedly contained residual traces of nitrate until further ignited.

THE EFFECT OF TEMPERATURE ON THE TOTAL VOLUME OF GAS OCCLUDED BY ZINCIC OXIDE.

First Series: Heated Three Hours.

(34)	1 gram of ZnO, after heating 3 hours at 660° ±, gave	0.365 c.c. gas.
(35)	" " " "	0.380 "
	Average	0.373 c c. gas.
(36)	1 gram of ZnO, after heating 3 hours at 750° ±, gave	0.233 c.c. gas.
(37)	" " " "	0.210 "
	Average	0.221 c.c. gas.
(38)	1 gram of ZnO, after heating 3 hours at 880° ±, gave	0.14 c.c. gas.
(39)	" " " "	0.18 "
	Average	0.16 c.c. gas.

Second Series: Heated Thirty Minutes.

(40)	1 gram of ZnO, after heating ½ hour at 750° ±, gave	0.366 c.c. gas.
(41)	" " " "	0.320 "
	Average	0.343 c.c. gas.
(42)	1 gram of ZnO, after heating ½ hour at 880° ±, gave	0.192 c.c. gas.
(43)	" " " "	0.192 "
	Average	0.192 c.c. gas.

Evidently, other conditions being equal, the total amount of gas retained decreases very considerably as the temperature of ignition is raised. Each one of these specimens of gas was analyzed, by means of Hempel's apparatus modified for use on a small scale,* with interesting results. The actual volume of *nitrogen* in every gram of material was found to be almost identical, diminishing only very slightly, if at all, as the temperature increased, and amounting to about 0.14 cubic centimeters. Thus the large differences in the total volumes are due almost wholly to *oxygen*, which varied from over sixty per cent in the first

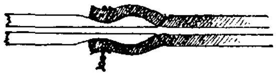

FIGURE 2.

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* The most important modification was the arrangement for connecting pipette to burette. By blowing and drawing down the capillary it may be made to fit so perfectly into the fine rubber tube as to make the loss of small bubbles impossible. The diagram will make the idea clear. (Fig. 2.)

average, to less than twenty per cent in the third. The small amount of carbon dioxide present was absorbed almost completely by the boiled water over which the gases were collected; hence it need not be considered.* The actual volumes of nitrogen in the five averages were respectively 0.138, 0.133, 0.130, in the first series, and 0.152 and 0.127 in the second series; while the actual amounts of oxygen were respectively 0.235, 0.087, 0.030 in the first series, and 0.191 and 0.065 in the second. No better proof could be desired of the fact that zincic oxide allows its oxygen to depart more easily than its nitrogen. These results are wholly confirmatory of the results of Richards and Rogers already mentioned; but of course they do not explain how Morse and Arbuckle, working at nearly constant temperature, obtained inconstant results. To accomplish this explanation, the other possible causes affecting the retention of gases must be considered.

THE EFFECT OF TIME OF IGNITION ON THE AMOUNT OF GAS RETAINED BY ZINCIC OXIDE.

First Series: Just above the Melting Point of Thallous Sulphate.

(44)	1 gram of ZnO, heated at 660° for 1 hour, gave	0.46 c.c. gas.
(34)	1 gram of ZnO, heated at 660° for 3 hours, gave	0.36 c.c. gas.
(35)	" " "	0.38 "
	Average	0.37 c.c. gas.

Second Series: Just above the Melting Point of Potassic Chloride.

(45)	1 gram of ZnO, heated at 750° for 10 minutes, gave	0.27 c.c. gas.
(46)	1 gram of ZnO, heated at 750° for 20 minutes, gave	0.35 c.c. gas.
(40)	1 gram of ZnO, heated at 750° for 30 minutes, gave	0.37 c.c. gas.
(41)	" " "	0.32 "
	Average	0.35 c.c. gas.
(47)	1 gram of ZnO, heated at 750° for 60 minutes, gave	0.30 c.c. gas.
(48)	" " "	0.32 "
	Average	0.31 c.c. gas.
(36)	1 gram of ZnO, heated at 750° for 180 minutes, gave	0.21 c.c. gas.
(37)	" " "	0.25 "
	Average	0.23 c.c. gas.

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* These Proceedings, XXVIII. 205, 209. In a number of cases where pains was taken to measure the carbon dioxide, its volume never exceeded three or four per cent, and was usually about two per cent.

Third Series: Just above the Melting Point of Sodic Sulphate.

(49)	1 gram of ZnO, heated at 880° for 3 minutes, gave	0.49 c.c. gas.
(50)	1 gram of ZnO, heated at 880° for 5 minutes, gave	0.35 c.c. gas.
(51)	1 gram of ZnO, heated at 880° for 12 minutes, gave	0.29 c.c. gas.
(52)	" " "	0.25 "
	Average	0.27 c.c. gas.
(42)	1 gram of ZnO, heated at 880° for 30 minutes, gave	0.19 c.c. gas.
(43)	" " "	0.19 "
	Average	0.19 c.c. gas.
(38)	1 gram of ZnO, heated at 880° for 180 minutes, gave	0.14 c.c. gas.
(39)	" " "	0.18 "
	Average	0.16 c.c. gas.

In each of the series the same fact may be noted, — the fact that continued heating at any one temperature is capable of causing a slow evolution of gas from the oxide. Only in the second of these series is evident an initial increase in the amount of gas, indicating a maximum after less than twenty minutes of heating. This increase, which is manifestly due to the advancing decomposition of the traces of imprisoned nitrate, undoubtedly ceases after an hour's heating at 660°, or after three minutes' heating at 880°; hence it does not appear in the first and third series.

The steady loss of gas after this maximum has been attained — a loss increasing with time as well as with increasing temperature in the case of *zincic* oxide — is worthy of further attention, especially because it will be remembered that the amount of gas retained by *cupric* oxide remained almost constant until a very high temperature was reached. Analysis of the several specimens of gas showed at once wherein lay the explanation; for they showed as before that the maximal quantities of gas consisted chiefly of oxygen; while the gas obtained by the last two experiments consisted chiefly of nitrogen. Here again the nitrogen remained nearly constant, only diminishing from 0.20 c. c. at the maxima to about 0.13 c. c. at the minima; while the oxygen diminished in the same samples from 0.21 c. c. to 0.03 c. c.

It remains only, as far as zincic oxide is concerned, to show how wide a difference in the amount of gas may be caused by the original mode of preparation of the solid material.

The Effect of Physical Condition upon the Total Amount of Gas retained by Zincic Oxide.

(53)	1 gram of ZnO, prepared from zincic carbonate at 880°, gave	0.00 c.c. gas.
(54)	" " " "	0.00 "
	Average	0.00 c.c. gas.
(55)	1 gram of ZnO, prepared from the nitrate at 280°, not ignited, gave	0.01 c.c. gas.
(56)	A similar experiment gave	0.02 "
	Average	0.015 c.c. gas.
(57)	1 gram of ZnO, prepared from zincic nitrate, but heated to 880° in a slightly reducing atmosphere, gave	0.05 c.c. gas.
(58)	A similar experiment gave	0.15 "
	Average	0.10 c.c. gas.
(42)	1 gram of ZnO, prepared by gentle heating of the nitrate at 280°, and subsequent ignition for 30 minutes at 880° in an oxidizing atmosphere	0.192 c.c. gas.
(43)	A similar experiment gave	0.192 "
	Average	0.192 c.c. gas.
(59)	1 gram of similar ZnO, prepared in the same way, but heated to 670° for 3 hours and then preserved two weeks before heating ½ hour at 880°, gave	0.292 c.c. gas.
(60)	A similar experiment gave	0.260 "
	Average	0.276 c.c. gas.
(61)	1 gram of more compact ZnO, prepared by heating the nitrate rapidly, and having been preserved for two weeks before being ignited for ½ hour at 880°, gave	0.387 c.c. gas.
(62)	A similar experiment gave	0.396 "
	Average	0.392 c.c. gas.

The evidence of these results proves that the total amount of gas retained by zincic oxide varies with every detail of the method of preparation; hence this amount cannot serve as a sure guide to the temperature of ignition, unless a perfectly uniform sample is used for all trials.* Of course the amounts of nitrogen found in these samples varied widely; for the gas resulted from the decomposition of zincic nitrate, which was imprisoned in varying quantities according to the physical condition of the zincic oxide.

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* Small quantities of such impurities as alkali and silica do not seem to affect the occlusion, however. See These Proceedings, XXVIII. 207.

Since so many circumstances regulate both the amount of gas and its composition, one is not surprised that Morse and Arbuckle obtained varying mixtures with eight different preparations of zincic oxide. It is true that their expulsion of the gases continued until it had become so slow that two successive weighings with intermediate heating gave constant weight; but the same causes of change must still have been at work, although far more slowly.

In the light of these interesting results, it seemed worth while to make a more elaborate investigation of the relation of the composition of the gases held by *cupric* oxide to the temperature used in its ignition. The material used in the following determinations was the soft powder made by the decomposition of cupric nitrate at 280°.

The Effect of Temperature of Ignition on the Composition of Gases retained by Cupric Oxide.

Time of Ignition, 1 hour.

(63) 0.32 c.c. gas from 1 gr. CuO heated at **520°** contained 18 per cent oxygen.
(64) 0.34 " " " " 15 " "
Average *15.5 per cent oxygen.*

(65) 0.49 c.c. gas from 1 gr. CuO heated at **660°** contained 6 per cent oxygen.
(66) 0.48 " " " " 5 " "
Average 5.5 per cent oxygen.

(67) 0.47 c.c. gas from 1 gr. CuO heated at **750°** contained 3 per cent oxygen.
" " " " " 4 " "
Average 3.5 per cent oxygen.

0.05 c.c. gas from 1 gr. CuO heated at **1000°** ± contained 0 to 4 per cent oxygen, according to Alexander Scott.

It is evident that the cupric nitrate remaining in the cupric oxide had not been wholly decomposed by heating for an hour at 500° (experiments No. 63 and 64) and that we are dealing here with an increasing total, and a maximum similar in every respect to that already noted in the case of zinc,* except that in the present case more nitrogen is held, while the oxygen escapes at a much lower temperature.

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* See page 412.

THE EFFECT OF TIME ON THE COMPOSITION OF THE GAS RETAINED BY CUPRIC OXIDE.

First Series: Temperature, 500°.

(Argentic Chloride easily melted; Plumbic Chloride scarcely melted.)

(68) 0.29 c.c. gas from 1 gr. CuO heated 2 hours contained 25 per cent oxygen
(69) 0.29 “ “ “ “ 23 “ “
Average 24 per cent oxygen.

(70) 0.38 c.c. gas from 1 gr. CuO heated 8 hours contained 15 per cent oxygen.
(71) 0.42 “ “ “ “ 14 “ “
Average 14.5 per cent oxygen.

(72) 0.46 c.c. gas from 1 gr. CuO heated 16 hours contained 8 per cent oxygen.

Second Series: Temperature, 520°.

(Just below the melting point of Argentic Iodide, but distinctly above that employed in the last series.)

(73) 0.15 c.c. gas from 1 gr. CuO heated for 15 min. contained 23 per cent oxygen.

(63) 0.32 c.c. gas from 1 gr. CuO heated for 1 hour contained 18 per cent oxygen.
(64) 0.34 “ “ “ “ 15 “ “
Average 16.5 per cent oxygen.

(74) 0.48 c.c. gas from 1 gr. CuO heated for 2 hours contained 12 per cent oxygen.

(75) 0.49 c.c. gas from 1 gr. CuO heated for 16 hours contained 6 per cent oxygen.

Third Series: Temperature, 600°.

(Argentic Iodide fused easily; Lithic Chloride fused slowly.)

(76) 0.43 c.c. gas from 1 gr. CuO heated for 10 min. contained 12 per cent oxygen.
(77) 0.38 “ “ “ “ 12 “ “
Average 12 per cent oxygen.

(78) 0.46 c.c. gas from 1 gr. CuO heated for 20 min. contained 13 per cent oxygen.

(79) 0.53 c.c. gas from 1 gr. CuO heated for 35 min. contained 10 per cent oxygen.
(80) 0.51 “ “ “ “ 8 “ “
Average 9 per cent oxygen.

Fourth Series: Temperature, 640°.

(Thallous Sulphate just fused; Strontic Nitrate remained solid.)

(81) 0.21 c.c. gas from 1 gr. CuO heated for 2 min. contained 35 per cent oxygen.
(82) 0.19 “ “ “ “ 36 “ “
Average 35.5 per cent oxygen.

(83) 0.43 c.c. gas from 1 gr. CuO heated for 10 min. contained 19 per cent oxygen.
(84) 0.45 " " " " 16 " "
Average 17.5 per cent oxygen.

(85) 0.46 c.c. gas from 1 gr. CuO heated for 8 hours contained 6 per cent oxygen.
(86) 0.45 " " " " 4 " "
Average 5 per cent oxygen.

It is clear that we are dealing here with a phenomenon precisely similar to that observed in the case of zinc. The decomposition of the remaining traces of nitric anhydride takes place much more slowly at low temperatures than at high ones, and the oxygen formed by this decomposition is liberated far more rapidly during the hotter ignitions.

A single series of experiments,* made some years ago with magnesic oxide, showed that this substance too acted in the same way, and it is probable that all the other oxides retaining traces of occluded gases would give similar results. The data obtained from magnesic oxide are repeated below, in order that all the facts may be at hand for the following consideration of the causes of the anomaly.

GAS EVOLVED FROM MAGNESIC OXIDE.

(*Temperature of Ignition was about* 700°–800°.)

1 gram MgO	after ignition	30	minutes gave	3.60	c.c. nitrogen and	7.2	c.c. oxygen.
1 gram MgO	"	60	"	4.72	"	6.3	"
1 gram MgO	"	75	"	4.84	"	4.4	"
1 gram MgO	"	135	"	5.44	"	3.6	"
1 gram MgO	"	195	"	5.24	"	2.8	"

HYPOTHETICAL EXPLANATION.

The facts are now perfectly clear, and it remains only to account for them by means of a plausible theory. In the first place, there can be no question that the gases proceed from a residue of basic nitrate imprisoned in the oxides in question ; the fact that oxides prepared from the carbonates contain little or no gas would alone be sufficient support for this point of view. The first matter to be considered is, then, the dissociation of this residual nitrate, which is probably wholly analogous to that of calcic carbonate as studied by Le Chatelier.† We may express this reaction, perhaps, in the following fashion, which indicates that the proceeding is supposed to take place in the gaseous phase, while the solids enter into the reaction solely by their vapor tension.

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* These Proceedings, XXVIII. 209.

† Compt. Rend., CII. 1243 (1886). Nernst, Theoret. Chem., p. 377 (1894).

$$\begin{tikzcd}
\underset{\text{Vapor.}}{\mathrm{Cu(NO_3)_2 \, . \, 3\,CuO}} \arrow[r, shift right] \arrow[d, shift right] & \underset{\text{Vapor.}}{\mathrm{4\,CuO}} + [\mathrm{N_2O_5}] \arrow[l, shift right] \arrow[d, shift right] \\
\underset{\text{Solid.}}{\mathrm{Cu(NO_3)_2 \, . \, 3\,CuO}} \arrow[u, shift right] & \underset{\text{Solid.}}{\mathrm{4\,CuO}} \arrow[u, shift right]
\end{tikzcd}$$

It is probable that Graham's basic cupric nitrate $Cu(NO_3)_2 \, . \, 3\,Cu(OH)_2$ is dehydrated before the nitric acid begins to leave; if it is not, of course three molecules of water must be added to the products above. The addition of the water does not affect the essential point in the following logic, however. The gaseous products of this reaction attain a pressure of 760 millimeters at about 280°.

The reaction represented above is evidently only a preliminary stage of the whole change; it may have scarcely begun, or may have run almost to an end in some cases before the dissociation of the nitric anhydride begins to enter into the problem. This dissociation may be complete, resulting in a mixture of the elementary gases, or it may (and does at ordinary pressures) stop at one of the lower oxides of nitrogen. Since the gases, whatever they may be, are necessarily held in microscopic cells, while their own volume under ordinary pressure is several times that of the total volume of the solid containing them, it is obvious that the pressure under which they exist must be very great. At this great pressure the stability of N_2O_5 must be very considerably increased, for the reaction $2\ N_2O_5 = 2\ N_2 + 5\ O_2$ is one which pressure must seriously affect because of the change of volume concerned in it; but more probably the peroxide of nitrogen may be the first product of the reaction. In any event, it is evident that the complete separation of the oxygen and nitrogen does not take place immediately, for much less nitrogen was yielded by the specimens of each oxide heated for a short time at comparatively low temperatures than by like specimens heated longer or hotter.

Both of these reactions, the decomposition of the cupric nitrate as well as that of the oxides of nitrogen, evidently then require time for their completion, so that the maximum of gas contents is not immediately attained. Besides being accelerated by heat they are also possibly both hastened by the escape of a portion of the oxygen, an interesting phenomenon which occurs side by side with the decomposition. To make the matter clearer, let us represent the dissociation of the oxide of nitrogen by the general formula

$$2\ NO_x = N_2 + xO_2.$$

The speed of this reaction is represented by the equation

$$-\frac{dc}{dt} = k\,c^2 - k^1\,c_1\,c_2^x,$$

an expression which increases in magnitude as c_2 (the concentration of the oxygen) diminishes. Since it is probable that k^1 is very small, — that the chief tendency of the reaction is from left to right, — this cause of acceleration is not an important one. In a similar way the decomposition of the oxides of nitrogen likewise accelerates the more complex reaction into which the solids enter.

In every case this decomposition of the oxides of nitrogen, and therefore that of the cupric nitrate, had nearly advanced to completion before the oxygen had all been expelled. This led to the existence of a maximum of gas volume after a brief heating, a maximum less marked in the case of cupric oxide than in the other cases because the extra oxygen escapes from cupric oxide almost as fast as it is formed. Thus many of the apparent eccentricities in the behavior of the gases find a simple and adequate explanation. The numerous results with different oxides were sought in the hope that the relations might be capable of quantitative proof according to the law of mass action, as well as of qualitative demonstration, but the great number of possible compounds and reactions made this hope vain.

It remains only to devise an hypothesis to explain perhaps the most interesting phenomenon under discussion, to show why the oxygen is capable of escaping more rapidly than the nitrogen. Obviously diffusion or transpiration cannot account for this; for any orifice, no matter how small, which would allow the oxygen to escape, must also allow the nitrogen to escape. The only possible explanation is the supposition that the oxygen finds its way out chemically, by uniting with metal or a lower oxide which has momentarily released some of its proper supply of oxygen. The displaced gas, being forced to find another berth, presently in its turn occupies the place of still another portion, and so on, until most or all of the excess has found its way out of prison. Of course the nitrogen cannot use this means of escape, for it is not surrounded by a compound which yields it upon dissociation; the nitrogen can only escape through holes originally present or formed by the rearrangement of the substance of the solid.

This hypothesis suggests Grotthus's obsolete explanation of electrolysis, or rather that of Clausius; for the most plausible conception is that in the hot rapidly vibrating solid a portion of the oxygen which ought to be combined with the metal is always in a free state, and that this condition, by a recurring process of dissociation and association, permits relieving the high pressure of the oxygen in the cell. It is possible that water occluded in the oxide may play the part of a go-between, but there is no experimental evidence of this. It is no new idea to explain the diffusion of hydrogen through palladium, or of carbon through iron in the cementation process, and other similar phenomena, by a similar mechanical conception.

Quite in accord with this point of view are a number of facts. In the first place cupric oxide, the most easily reducible of the oxides investigated, parts with its occluded oxygen with the greatest ease, at the same time obstinately retaining the nitrogen. The progressive increase in the tendency to retain oxygen in the cases of zinc and magnesium corresponds to the increase in the difficulty of reducing these oxides. In other words, the least stable oxide is the one which has the feeblest hold upon the occluded oxygen. Cupric oxide begins to lose this impurity with great rapidity at 520°, zincic oxide loses it less rapidly even at 750°, and magnesic oxide is still more obstinate. It is probable, moreover, that in the cases of zinc and magnesium there is a slight amount of transpiration, for a small part of the nitrogen was found to leave at the higher temperatures. This transpiration ought to assist the oxygen also to escape, although in somewhat less measure than the nitrogen; but in spite of this possibility of more rapid escape, the oxygen is still held more firmly than in the case of cupric oxide. In this latter substance all the *nitrogen* is retained indefinitely at temperatures below 850°, forming the constant gas residue noted in the first experiments; only when the definite structure of the oxide is broken up, and the dissociation tension of the cupric oxide becomes so great that cuprous oxide begins to be formed, does the nitrogen take its flight. On the other hand a reducing atmosphere is needed to force zincic oxide to relinquish all its gas, unless an excessively high temperature is employed. Forty-three years ago Sainte-Claire Deville and Rivot showed that at a red heat such an equilibrium exists between zincic oxide, zinc, hydrogen, and water as to enable zinc oxide to be sublimed in a current of hydrogen, the dissociated oxide reforming when cooled.* This reaction undoubtedly enables the occluded gas to escape by destroying the structure of the solid when gases from the flame are present.

Again, the fact that many solids, the oxides in question among them, manifest upon heating the peculiar contraction called "sintering," is evidence of the existence of molecular instability and possibility of rearrangement. The hypothesis of partial dissociation at high temperatures is adequate to explain this.

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* Ann. Chem. Phys., (3.), XLIII. 7, 477.

It is obvious that, if the oxide is really dissociated, it should be capable of conducting electricity, because of the presence of traces of metal. In order to test this point, small platinum electrodes of 0.25 square centimeter in area and separated from one another by about 0.5 cm. were packed in pure specimens of the several oxides. Each porcelain crucible containing an oxide was gradually heated, after having placed the two electrodes in a circuit with a delicate amperemeter and four accumulators. When cold, the resistance of each of the oxides was at least 200,000 ohms. Upon heating, the cupric oxide began sensibly to conduct below a red heat, and at about 650° offered only about as much hindrance to the current as was afforded by 550 ohms, remaining constant at that point. On the other hand, zincic oxide fell in resistance only to about 15,000 ohms at 650°, and required fully 900° to bring it as low as 1,000 ohms; while the highest heat of the blast lamp could not cause the magnesic oxide to transmit as much as the twentieth of a milliampere, the least current capable of being observed upon the amperemeter. It is needless to say that any possibility of the presence of a reducing atmosphere was excluded, and the fact that each oxide returned almost if not quite to its non-conducting state after cooling is sufficient proof that the heat alone was the cause of the phemomena observed. These interesting results are fully in accord with the hypothesis that cupric oxide is slightly dissociated at a red heat, that zincic oxide is less dissociated, and that magnesic oxide, retaining its occluded oxygen with great obstinacy, is scarcely dissociated at all. Magnesic oxide, being one of the stablest of all compounds at high temperatures, could not be expected to show any appreciable dissociation or conductivity; and the wonder is, that the occluded gas is able to escape even as fast as it does.

This assumed partial thermal dissociation of solids must not be confounded with electrolytic dissociation (ionization); for the energy which determines the separation of the components in the present case is heat, and not electricity. The conductivity is not electrolytic conductivity, but only the metallic conductivity of the metal set free by a purely thermal dissociation. In order to prove this, a current of twenty milliamperes was transmitted through cupric oxide for three hours. This quantity of electricity would have carried nearly seventy milligrams of copper from a cupric solution, and since neither copper nor an oxide appeared adhering to the platinum negative electrode, it is safe to infer that the conductivity is not electrolytic. While these oxides thus conduct electricity without transferrence of material, it is undoubtedly true that many substances, even glass for example, which are non-conductors when cold, become capable of carrying a current *electrolytically* when heated. Melted salts are well known to be good electrolytic conductors, and Graetz* has found that this conductivity begins before the salts have melted. Our knowledge of the rationale of these facts is altogether too incomplete to afford satisfactory explanation of all the phenomena attending the passage of electricity through solids, liquids, or gases at high temperatures; and it is perhaps unsafe to record the conductivity of cupric oxide as a definite indication of the temporary presence of metallic copper in the case under discussion.

Following is a more certain proof that this dissociation is to be considered as analogous to the decomposition of limestone by heat. Here, as there, the gas, in the present case oxygen, must have a definite pressure of dissociation; but no appreciable amount of metal or lower oxide can form when the tension of the oxygen in the surrounding atmosphere is greater than this definite pressure. On the other hand, cupric oxide should lose not only its occluded oxygen, but all the oxygen that normally belongs to it, leaving metallic copper (or at least cuprous oxide), when heated in a perfect vacuum or in an inert atmosphere, if the hypothesis under consideration is tenable. This begins even in the air at about 1,000°. The search in chemical literature revealed a statement by Hilditch that cupric oxide ignited at lower temperatures in a vacuum weighs less than it did before, as well as one by Morley that the same substance slowly evolves a gas when heated in a vacuum.† Since it is hard to tell whether this evolution might not be merely that of the occluded gases, it was thought worth while to repeat the experiment.

Two grams of cupric oxide, which had been ignited for a long time in pure air until constant in weight, were found to evolve a gas steadily when heated in a vacuum to about the melting point of common salt (790°), provided that the gas was removed by a Sprengel pump as fast as it was formed. When allowed to attain equilibrium, this gas (which repeated analysis showed to be almost pure oxygen containing only traces of nitrogen and carbon dioxide) was found to possess a tension of two or three tenths of a millimeter of mercury. A portion of the same material was heated for many hours more in a crucible to a full red heat; but upon subsequently heating it in a vacuum the evolution of gas proceeded just as before. Since all the occluded oxygen except two or three per cent had been expelled by the preliminary heating, this must have been structural oxygen. The conclusion was confirmed by the discovery of red cuprous oxide in the residue. Repetitions of the experiment showed that the tension of the gas increased enormously with the temperature, exceeding a millimeter before the glass became so soft as to collapse. In some of the experiments the best Bohemian glass was used, in others the hardest made in Jena. The nature of the glass seemed to be without influence on the result. The amount of gas evolved in a given time naturally depends upon the efficiency of the pump, as well as upon the temperature; in one of the experiments two cubic centimeters of oxygen were obtained in eight hours.

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* Wied. Ann., XL. 18 (1890).

† Hilditch, Chem. News, XLIX. 37 (1884). Morley, Am. J. Sci., XLI. 231 (1891).

Ignition of the substance in an inert atmosphere should produce the same effect. Since cupric oxide is slightly dissociated by heat, perceptible amounts of oxygen should be removed by heating it in nitrogen, just as carbonic acid is removed from limestone by heating it in a current of air. This dissociation of cupric oxide must have its effect on any process involving the ignition of cupric oxide in a vacuum or in an inert gas. The determination of organic nitrogen by means of the Sprengel pump, for example, must be affected by it. The use of carbon dioxide as a displacing medium in the Dumas method probably disposes of the error, however; for carbon dioxide is itself dissociated by heat, and it undoubtedly furnishes enough oxygen to diminish greatly the decomposition of the cupric oxide.

In the light of these results, it is obviously advisable, when one desires to remove oxygen from a mixture of gases by means of hot copper, to maintain the last portion of the tube at a comparatively low temperature. Even then the issuing gas may not be absolutely free from oxygen.

Every one knows that auric oxide is excessively unstable, and that argentic oxide is completely decomposed even in an atmosphere of pure oxygen at comparatively low temperatures. The present results merely extend this behavior, in a much smaller degree, to cupric oxide, and the hypothesis carries the idea still further. The dissociation of zincic oxide must of course be yet less, while the tension of oxygen above magnesic oxide even at high temperatures must be an infinitesimal far less in value than the tension of the gas in the vacuum needed for the production of X-rays.

According to the phase rule and the law of mass action these reactions must take place in the gaseous phase, — the only one present of variable composition. As an example, the case of copper is given below: —

$$\begin{array}{ccccc} 4\,\mathrm{CuO} & \leftrightarrows & 2\,\mathrm{Cu_2O} & + & \mathrm{O_2} \\ \text{Vapor.} & & \text{Vapor.} & & \text{Gas.} \\ \uparrow\downarrow & & \uparrow\downarrow & & \\ 4\,\mathrm{CuO} & & 2\,\mathrm{Cu_2O} & & \\ \text{Solid.} & & \text{Solid.} & & \end{array}$$

The occluded oxygen is supposed to escape by the oscillation, backward and forward, of this heterogeneous reaction. The ability of the system to be first dissociated and then associated in another place where more oxygen is present presupposes, however, great internal activity in the substance of the hot solids; and this internal activity is the most interesting conclusion to be drawn from the phenomena under discussion.

In short, no matter what point of view one adopts, or what mechanical picture one forms of the reaction, the necessity of ascribing the rapid escape of the oxygen to internal rearrangement seems to be inevitable.

Professor Morse, in another letter received since the foregoing was written, kindly tells me that, in the course of some admirable work upon the atomic weight of cadmium which he has just completed, he has had occasion to measure the gases occluded by cadmic oxide made from the nitrate. As one would expect, this oxide holds its occluded oxygen more firmly than copper, but less firmly than zinc. In fact, the behavior of the substance, according to Professor Morse's description, probably accords well with the hypothesis under consideration. His interesting results will soon be in print, and will speak for themselves. The fact that Rogers and I found no gas in our cadmic oxide in 1892 is easily accounted for by the circumstance that we used a bright red heat in the ignition, the oxide parting with both gases by the disintegration of its original structure, as the oxide of copper did with Scott. Since cadmium is volatile at high temperatures, however, it was natural that its dissociated oxide should have a wider opportunity of rearrangement than in the case of copper; and hence the crystalline structure of the ignited oxide observed in 1892. Nickel, another metal whose oxide was investigated by Rogers, probably occupies its expected place near cadmium, as far as its oxide's capacity to retain oxygen is concerned. In some recent experiments in this laboratory, Cushman succeeded in partially decomposing nickelous oxide in a stream of nitrogen below 1200°. All these considerations are concordant with the hypothesis devised to explain the escape of occluded oxygen for metallic oxides.

The only point regarding this occlusion of gases left unexplained is the fact that in the experiments of Morse and Arbuckle the total amount of gas was in every case nearly the same, although the proportion of oxygen and nitrogen varied. This is a very interesting circumstance. The experimenters ignited their oxide to constant weight, in other words, until two successive ignitions caused no appreciable change; but it does not follow from this that the evolution of gas had ceased, — one can only maintain that it had become so slow as to be inappreciable. Evidently, then, the question to be answered is, — Why has the oxygen more difficulty in escaping when a small amount of nitrogen is present than when a large amount is present? The reason of this eccentricity may be because those specimens which contain the most gas are naturally the most porous and loosely held together, although usually formed in larger individual aggregations; and the freer atomic and molecular motion allowed by the looser structure permits the oxygen to leave more rapidly. Hence in each case the sum of the oxygen and nitrogen amounted to about the same volume. This hypothesis within an hypothesis is rather too uncertain to deserve much emphasis, however.*

In the course of some of my old experiments on the impurities in cupric oxide, it became necessary to reduce the substance in a current of carbon monoxide. Referring to this work, Dr. A. Scott, in the paper already cited,† expresses surprise at the existence of an admixture of hydrogen in this gas. His experience agrees with that of Stas in finding only a small amount of such gaseous impurity in carbonic oxide obtained from oxalic acid, while my results indicated a large amount. Lord Rayleigh, in the course of his recent valuable work on the density of gases,* concludes that his carbonic oxide also was free from hydrogen or hydrocarbons; and indeed there is no reason why this result should not be easily attained if one uses pure materials. Lord Rayleigh explains the existence of hydrogen in my carbonic oxide by drawing attention to the fact that in my case the gas, dried only by calcic chloride, was passed over red hot platinum sponge.

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* In this connection it is a matter of interest to note that Ramsay (Phil. Mag., (5.), XXXVIII. 206 [1894]) has found that the presence of nitrogen in a palladium bulb seems to prevent to some extent the diffusion of hydrogen into it. This observation is not unlike Morse and Arbuckle's; but if as a matter of fact an indifferent gas can produce such an effect, our present notions concerning semipermeable septa demand some revision.

† *Loc. cit.*, p. 563.

This explanation is undoubtedly correct. Many experimenters have shown that the reaction $CO + H_2O = H_2 + CO_2$ is an easily reversible one at high temperatures,† and in the presence of a large excess of carbon monoxide, it is obvious that nearly all of the trace of aqueous vapor would be reduced. For my purpose at the time, the source of the hydrogen was of no importance; it was only necessary to know the exact amount of the impurity, and this was suitably determined. It is satisfactory to know the cause of the discrepancy, however, as well as to know that it is easier to prepare carbon monoxide almost free from hydrogen than seriously contaminated with it. More often than we suspect, perhaps, are our carelessly planned efforts at purification apt thus to introduce more impurity than they eliminate.

In a recent number of the Journal of the American Chemical Society, (March, 1898,) F. R. M. Hitchcock has published a preliminary paper upon the occlusion of various gases by the oxides of metals, having apparently overlooked the Harvard investigations. It is satisfactory to see the phenomenon widely recognized; for an appreciation of this serious cause of possible constant error will result in the publication of fewer erroneous determinations of atomic weights than have appeared in the past. One should also bear in mind the fact that nitric acid is not by any means the only substance which is liable to leave appreciable contamination in material from which it has been expelled by heat. The number of such occlusions is far greater than most analysts imagine; this fact is not realized because the minute residues are often so hard to detect.

The evidence of this paper proves that in reality no discrepancy exists between the results of Scott, and Morse and Arbuckle, and those obtained at Harvard. The apparent disagreements were caused by the fact that the later experimenters investigated parts only of the wide field outlined in 1892, the relation of the parts to the whole being partially unperceived. The paper also shows that the unequal escape of oxygen and nitrogen imprisoned in the oxides of metals is a phenomenon of great interest, capable of shedding light on the internal kinetics of solids.

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* Proc. Roy. Soc., LXII. 204 (1898).

† Bunsen, Liebig's Annalen, LXXXV. 137 (1853). Horstmann, Ibid., CXC. 228 (1878). Bötsch, Ibid., CCX. 207. And especially Hoitsema, Zeitschr. Phys. Chem., XXV. 688, as well as others.

CAMBRIDGE, May 1, 1898.

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CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL MUSEUM.

I. *OCCURRENCE OF NATIVE COPPER AT FRANKLIN FURNACE, NEW JERSEY.*

II. *EXHIBITION AND PRELIMINARY ACCOUNT OF A COLLECTION OF MICROPHOTOGRAPHS OF SNOW CRYSTALS, MADE BY W. A. BENTLEY.*

BY J. E. WOLFF.

COMMUNICATIONS FROM THE HARVARD MINERALOGICAL MUSEUM.

OCCURRENCE OF NATIVE COPPER AT FRANKLIN FURNACE, NEW JERSEY.

BY J. E. WOLFF.

Presented April 13, 1898.

In 1897 a large specimen of ore containing native copper from the new (Parker) shaft at North Mine Hill, Franklin Furnace, was acquired for the Harvard Mineralogical Museum.

The specimen, some seven inches square, is broken flat parallel to the banding of the ore body, and is composed of a central band of apple-green willemite interbanded with coarse white calcite and smaller masses of franklinite and zincite in the usual association. The cleavage surfaces of the calcite masses are curved by pressure, and show the development of the gliding planes parallel to $-\frac{1}{2}$ R. In the central zone of the specimen these evidences of pressure become intensified, and small slickensided surfaces are developed in the willemite and calcite, while the former mineral is irregularly cracked in addition to the development of the imperfect cleavage. In this zone native copper occurs, forming a band half an inch wide running parallel to the banding of the ore. The copper has no distinct crystalline form, but occurs as thin films or thicker sheets filling the cracks in the willemite and occasionally in the calcite. Except for traces of oxidation on its surface, the copper is pure and associated with no other mineral.

Of two other specimens loaned by Mr. J. A. Van Mater, superintendent at North Mine Hill, one has the same association described above, and shows a veinlet of copper penetrating calcite along a gliding plane, in addition to the penetration along fissures in the willemite. In the other the copper occurs in willemite which is associated with yellow garnet, black biotite, and calcite. The masses of copper are thicker here, and a projecting point laid bare by the removal of the matrix has some resemblance to a spear-head twin of copper, but is probably a matrix mould.

In May, 1898, small sheets of native copper were seen by the writer in vein matter coming up from the deep levels, but have not yet been observed in the standing vein. The matrix is a light yellow densely granular mineral with resinous lustre, which appears from preliminary tests to be a phase of the yellow manganese garnet (polyadelphite) so common in the vein matter of the Parker shaft. It is intimately mixed in microscopic veinlets and larger masses with an amorphous (often earthy) light pink manganese mineral not further identified. A thin section of this gangue shows cloudy yellow spots of the garnet surrounded by paler transparent material which has the feeble double refraction in sectors of some garnet, a property which has not been observed by the writer in the ordinary deep yellow garnet of the ore body. This abnormal character and the veining by the pink material suggest an alteration of the original garnet gangue with which the deposition of the copper might have been contemporaneous.

Mr. Van Mater states that native copper occurred in 1897 about eight hundred feet below the surface in a seam in the middle of the ore body, i. e. about half way between the hanging and foot walls. This seam was filled with a gangue of rhodonite and other minerals in an earthy porous condition, and probably represents the form just described.

The other occurrence in massive willemite was not observed in the standing vein, but was picked out from the ore coming from about the same depth.

It is evident, from the relations of the veinlets of the copper to the cleavage and cracking of the willemite and secondary pressure planes of the calcite, that its deposition took place *after* the formation of the zinc ores and associated minerals, and that possibly the circulation of the solutions from which it was deposited took place along the same motion planes in the ore body which produced the beautiful slickensides found occasionally in this part of the deposit. There are no facts on which to base a conclusion as to the form in which the copper was carried in solution, nor as to the method of its final reduction and deposition, although it is probable the changes noticed above in the garnet gangue were connected with it.

This occurrence increases the long list of minerals found at Franklin Furnace and vicinity (now nearly seventy), and is an interesting addition to the occurrences of native copper below the zone of surface oxidation.

EXHIBITION AND PRELIMINARY ACCOUNT OF A COLLECTION OF MICROPHOTOGRAPHS OF SNOW CRYSTALS, MADE BY W. A. BENTLEY.

By J. E. Wolff.

Presented April 13, 1898.

The study of snow crystals dates back to the middle of the sixteenth century, when the first drawings appeared in the book of Olaus Magnus in 1555, and other early authors, including Des Cartes and Keppler, have described and figured these forms. In 1820, William Scoresby published 96 drawings of snow crystals made in the Arctic regions, in 1855 J. Glaisher 150, and in the same year Franke 119.

The first reproduction of microphotographs of snow crystals was in the small monograph of G. Hellmann in 1893 with about 60 examples,* and in the same year G. Nordenskiöld published about the same number.† In 1894 Hellmann published a plate of much larger pictures taken by a Russian photographer.‡

The present collection has been made by Mr. W. A. Bentley of Nashville, Vermont, during the last twenty years, and includes about 400 of the most interesting examples out of a total of 550 made by him. Through the disinterestedness of Mr. Bentley the collection has been acquired at a nominal cost for the Harvard Mineralogical Museum for study and public exhibition.

Its scientific value is enhanced by his notes, which comprise a number of meteorological observations made by himself at the time many of the sets from individual storms were made, including date, temperature, snow fall, condition of the clouds, direction and force of the wind, and sometimes notes as to the general character of the snow crystals and their changes as the storm progressed.

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* Schneekrystalle-Beobachtungen und Studien, by Professor G. Hellmann, with eleven cuts and eight heliogravures after the micro-photographs of R. Neuhauss, M. D. Berlin, Rudolph Muckenberger. The historical summary given above is taken from this work.

† Preliminary Communication concerning an Investigation of Snow Crystals. Geol. Foren. i Stockholm. Forh. Bd. 15, pp. 146–158. 1893. English summary in Nature, Vol. XLVIII. pp. 592–594.

‡ Meteorologische Zeitschrift, 1894, p. 281.

The magnifications used range from 52 to 31 diameters, and are evidently much higher than those of previous collections. The same general types of crystals noticed by previous observers recur here, such as the star form, star form with solid nucleus, and tabular form, while the columnar form (hexagonal prism and base) is rare, and the hexagonal pyramid is not seen. Variations of skeleton growth of hexagonal plates, comprising the base and prism of the first order, predominate; less commonly the intermediate axes are visible by lines of growth or air inclusions, and rarely a triangular development suggests rhombohedral symmetry. The presence of the varied markings due to inclusions of air is much more prominent in these than any as yet published, owing to the higher magnification and the superb technique of the photographs. Mr. Bentley also confirms the previous observation, that large stellate crystals are more common at the higher temperatures and the tabular ones at the lower.

Some photographs of frost crystallizations are included.

Reserving for a future communication the result of more detailed study, a preliminary account is here given of this large and perfect collection which may justly be called a monument to the patience, skill, and enthusiasm of the maker.*

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* In " A Study of Snow Crystals," recently published in Appleton's Popular Science Monthly, (May, 1898, pp. 75-82,) by W. A. Bentley and G. H. Perkins, the authors give some account of this collection, with a reproduction of 27 examples.

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AN INQUIRY INTO THE NATURE OF ELECTRICAL DISCHARGES IN AIR AND GASES.

By John Trowbridge.

With Three Plates.

Investigations on Light and Heat, made and published wholly or in part with appropriation from the Rumford Fund.

AN INQUIRY INTO THE NATURE OF ELECTRICAL DISCHARGES IN AIR AND GASES.

By John Trowbridge.

Presented March 9, 1898.

In a previous communication* I have described with some detail the installation of a storage battery of ten thousand cells, and I gave a preliminary account of some of the effects produced by this battery. It seemed desirable to utilize to the utmost its ability to produce high electromotive force. Hitherto investigators have been limited to a comparatively narrow range of inquiry on this subject; and this paper therefore contains an account of an incursion into what may be termed a new region, in which matter is subjected to an unusual electrical stress.

The discharge from a large number of Planté cells is characterized by a sibillant flame, which, by quickly separating the spark terminals, can be drawn out to a length of several feet. It closely resembles the light produced by passing an electric spark through lycopodium powder. When a photograph of this flaming discharge is examined, it is seen to have an intensely bright spark as a nucleus. On account of the flaming discharge it is difficult to examine its character by means of a revolving mirror. By employing, however, two spark gaps, it seemed possible to ascertain whether the discharge is oscillatory or not.

In my experiments the circuit was made at the instant the revolving mirror was in the position to reflect an image of the discharge of the battery upon a sensitive plate. The photographs obtained in this way showed disruptive discharges superimposed upon a continuous discharge. The latter, however, masked any appearance of an oscillatory discharge. It was evidently necessary to blow out the flaming discharge in order to see if oscillations followed the pilot discharge. The first experiment was made with 2500 cells arranged in series; and the flaming discharge was much lessened both by the reduction in the number of cells and by a suitable arrangement for blowing it out. On developing the photographs it was found that the discharge was an oscillatory one; for as many as five or six clearly defined oscillations followed the first, or pilot discharge. The number of cells was then doubled; and, although more difficulty was experienced with the flaming discharge, oscillations were again obtained.

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* These Proceedings, XXXII. 253.

On the supposition that each cell of the battery can be regarded as a leaking condenser, and that it is equivalent in capacity to a condenser shunted by a resistance equal to that of the electrolyte, we can treat such a cell as a conducting condenser under the influence, during discharge, of a periodic current. The analysis of this well known case is as follows.*

Let $A\,B\,C$ and $A\,E\,C$ be two circuits, the circuit $A\,B\,C$ being a shunt to the circuit $A\,E\,C$, which contains a condenser E.

Let L be the coefficient of self-induction of $A\,B\,C$, R its resistance, C the capacity of the condenser in the circuit $A\,E\,C$, and r the resistance of the wires leading to the plates of the condenser.

Then, if i is the current through $A\,B\,C$, and x the charge on the plate nearest to A,

$$L\frac{d\,i}{d\,t} + R\,i = r\frac{d\,x}{d\,t} + \frac{x}{c}.$$

Since each of the quantities is equal to the electromotive force between A and C.

If $i = \cos\rho\,t$,

$$\text{then } x = \frac{(L^2\rho^2 + R^2)^{\frac{1}{2}}}{\left(\frac{1}{C^2} + r^2\rho^2\right)^{\frac{1}{2}}}\sin(\rho\,t + a),$$

$$\text{where } a = \tan^{-1}\frac{L\rho}{R} + \tan^{-1}\frac{1}{r\,\rho\,C}.$$

$$\text{Hence } \frac{d\,x}{d\,t} = \frac{\sqrt{L^2\rho^2 + R^2}}{\frac{1}{C^2\rho^2} + r^2}\cos(\rho\,t + a).$$

Thus the maximum current along $A\,E\,C$ is to that along $A\,B\,C$ as

$$\sqrt{L^2\rho^2 + R^2} \text{ is to } \sqrt{\frac{1}{C^2\rho^2} + r^2}.$$

Or if we neglect the resistance r of the leading wires, as

$$\sqrt{L^2\rho^2 + R^2} : \frac{1}{C\,\rho}, \text{ or, neglecting } L, \text{ as, } \frac{R}{\frac{1}{C\,\rho}}.$$

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* See Elements of Electricity and Magnetism, by Prof. J. J. Thomson, p. 431.

In the case of one cell of the battery the polarization capacity is undoubtedly very large. C. M. Gordon* finds that the polarization capacity of two surfaces of platinum 0.65 cm.^{2} separated by an interval of 2 mm. amounts to more than 50 microfarads. The cells of my battery consist of lead plates of about 10 cm.^{2} surface separated by about 6 mm. The layer of peroxide of lead undoubtedly gives a large polarization capacity. The resistance of each cell is about one quarter of an ohm. Even with this small value of R, oscillating currents such as my experiments show arise when the battery discharges through air or gases. A large portion of the oscillating currents pass through the condenser circuit, and the electrolyte acts as a semi-insulator. With a very high value of p, no current would pass through the electrolyte, and the cells would therefore act like Leyden jars. In the case I am considering, the Planté cells evidently act like leaky Leyden jars coupled in series. If C is the apparent capacity of one cell, $\frac{C}{n}$ would be the capacity of n cells.

An examination of the photographs of the oscillations produced by 2,500 cells, showed an apparent capacity of about 1,000 electrostatic units. Five thousand cells gave an apparent capacity of about 500 electrostatic units, as should be the case. The small apparent capacity C results from the leaking of the condenser due to the conduction through the electrolyte.

Since the discharge from an accumulator of a large number of cells is, in general, oscillatory, I am led to the belief that the discharge from any primary battery is also oscillatory, for in all cases we have to deal with capacity and self-induction. It is evident that a galvanometer in circuit with a Geisler tube or a telephone cannot detect the oscillatory discharge, since it is of high period. Moreover, when a Geisler tube is lighted by a large battery with no resistance save that of the Geisler tube and the battery in the circuit, and the light is examined in a revolving mirror by the eye, no oscillations or intermittence of light can be perceived on account of the flaming discharge through the rarefied gas.

The oscillatory discharge may be said to be the common occurrence of nature in the case of electrical discharges, and the one direction discharge the uncommon. This has been expressed by the remark that electricity takes the path of least resistance ; this common belief, however, must be modified under certain conditions of resonance. In general, nature avoids a unidirectional discharge.

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* Wied. Ann., No. 5, 1897, p. 28.

A large storage battery exhibits in an interesting manner the time necessary to change condensers to a definite potential. When the inner coating of a Leyden jar of about 10,000 electrostatic units is connected with one pole of the battery, and the other rests upon a wooden table upon which the Leyden jar is placed, this jar will discharge through a small spark gap once in about ten seconds. When this latter terminal is connected directly with the outer coating of the jar, the rapidity of discharge increases to at least one hundred a second, and appears to the eye to be continuous. The battery acts like a reservoir, and continually supplies the loss in the jar. I was interested to ascertain whether the capacity in the circuit influenced the breaking down effect in air and in oil. Without external capacity boiled linseed oil broke down between small spheres — at a distance of one millimeter — under a difference of potential of 20,000 volts. A sheet of microscopic cover glass $\frac{1}{250}$ of an inch in *thickness was not, however, perforated, and a sheet of mica* $\frac{1}{1000}$ *of an* inch in thickness also withstood this difference of potential. When a capacity of 10,000 electrostatic units was employed no difference could be observed in the breaking down effect. When therefore a powerful storage battery is employed to generate a difference of potential, it apparently serves the purpose of maintaining a full difference of potential between terminals, and an external capacity does not influence the breaking down effect.

The experiments I have described on the electric strength of thin layers of glass showed that a number of Franklin plates one tenth of an inch in thickness could be charged in multiple and discharged safely in series. I had constructed at first an apparatus similar to that described by Planté. I speedily found, however, that the design employed by him would not enable me to utilize the full energy of 10,000 cells, for short circuiting would occur in the apparatus. The form described by Planté was therefore replaced by the one shown in Plate I., and in plan and elevation in Plate II. (Figs. 1 and 2).

Figure 1, Plate II., represents an elevation of one end of the apparatus, and Figure 2 a plan of this end. The condensers are shown at C in Figure 1, but are not represented in Figure 2, in order that the connections may be more clearly seen. In Figure 1, H is a handle which moves by means of the link work D both levers L and L' at once. When the lever L is lowered, conductors running along a and a_1 are brought in contact with the coatings E and E' of the plate condensers, C connecting them in multiple. At the same time the lever L' is lifted. When, however, the lever arm L is lifted, L' descends until the diagonal connector running along b and b' are brought in contact with the coatings E and E' in such a manner as to connect them in series. The conductors connected with the lever arm L extend beyond the connecting arm D, in order to make connection with the terminals of the storage battery B. This extension is necessary in order to prevent any possibility of a return discharge through the battery. T represents one of the terminals of the machine, — which is a special arrangement of the apparatus consisting of spheres one foot in diameter, and thus give a scale of estimation of the size of the apparatus. There are one hundred and fifty plate condensers forty by fifty centimeters.

Lord Kelvin, in a paper dated April 12, 1860,* entitled "Measurement of Electromotive Force required to produce a Spark," states that "there is a much less rapid variation with distance of the electrostatic force preceding a spark at the greater than at the smaller distance. It seems most probable that at still greater distances the electrostatic force will be found to be sensibly constant, as it was certainly expected to be at all distances."

Professor Elihu Thomson, by means of transformers, has obtained sparks of fifty to sixty inches in length, and has estimated the necessary voltage to produce a spark of 80 cm. at 500,000.

This estimate A. Heydweiler † thinks is very much too great, and he believes that 100,000 would be nearer the truth. My investigations show conclusively that the estimate of Professor Thomson is far nearer the truth than that of Heydweiler, and instead of being lessened it should be increased.

In a late paper on the tension at the poles of induction apparatus, A. Oberbeck ‡ states that a potential difference of 60,000 volts under given conditions can produce a spark of more than 10 cm. in length. It is difficult to obtain consistent results by the use of induction coils and transformers.

My results show that Lord Kelvin's conjecture, that the electrostatic force necessary to produce a spark in air remains sensibly constant for all distances beyond the limit he describes, is correct up to the voltage of one million; for when the length of spark is plotted as abscissas, and the corresponding electro-motive force as ordinates, a straight line is obtained. Planté calls attention to the fact that the loss of energy resulting from the transformation of dynamic into static electricity is in the case of his apparatus much less than in induction apparatus. This remark applies with great force to the modern use of transformers for the production of high tension effects. With the improved form of rheostatic machine which I have had constructed, one third of a horse-power will produce the effects which have hitherto required the employment of thirty to forty horse-power.

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* Papers on Electrostatics and Magnetism. Macmillan, London, 1872, p. 258.

† Wied. Ann., No. 48, p. 231, 1893.

‡ Wied. Ann., No. 9, p. 109, 1897.

Up to the point of one million and a half volts the length of the electrical discharge in air appears to be closely proportional to the electromotive force. When this voltage is exceeded, the length of the spark no longer increases in proportion to this force. For instance, an electromotive force of approximately three million produces a spark of about seven feet in length, two hundred and ten centimeters, when it should excite one at least ten feet in length. The reason of this diminution in length is readily seen when the operation of my apparatus is examined in the dark. From both terminals and from the conductors to the terminals there is a luminous brush discharge to the walls and floor of the room. The main discharge between the terminals is so to speak shunted through the air, which breaks down with facility at such high voltages. The high electromotive force exerts a similar action to that of diminished air pressure.

It is thus interesting to compare these conditions further. I therefore connected in multiple two Leyden jars, of about five thousand electrostatic units each, with the poles of five thousand of my cells, and measured the disruptive discharge in a receiver which contained air at ten centimeters pressure. The length of the discharge at this pressure was approximately eight centimeters, when the jars were charged with ten thousand cells. The length of this discharge was fourteen centimeters. Here twice the voltage did not produce twice the spark length. The diminution of length was evidently due to a species of shunting through the air, which had become a relatively good conductor. Indeed, one sees the luminous area of discharge on the positive terminal extend farther and farther in the case of pointed terminals from the point of the terminal.

In ordinary atmospheric air, therefore, the same increase of electrical conductivity takes place under the action of great electromotive force. It is difficult to make exact measurements of the action of such powerful discharges; but the following qualitative experiments, I think, will illustrate my meaning. When discharges produced by one million volts and over are excited between terminals six feet apart in tubes filled with ordinary water, the tubes are speedily burst, and when the phenomenon is carefully examined it is perceived that disruptive sparks occur on the surface of the water inside the tubes which vaporize the water and thus lead to an explosion. The layer of air conducts more readily than the water. The same phenomenon can be shown by interposing a conductor made of plumbago and infusorial earth of about ten thousand ohms resistance between the terminals of the apparatus. A spark passes over the surface of such a conductor through the air, if the length of such a conductor does not exceed ten or twelve inches. The breaking down resistance of atmospheric air for such high voltages between terminals this distance apart is therefore less than ten thousand ohms. The same phenomenon is observed in the case of paraffine oil, which exhibits between pointed terminals a resistance of only a few thousand ohms for distances of six to eight inches. The actual resistance after breaking down falls to two or three ohms. This I have shown in a previous paper.* To still further study this breaking down of air insulation I carefully measured by Kohlrausch's Bridge method a liquid resistance consisting of diluted sulphate of copper of about one thousand ohms. The terminals in the tube were disks of copper about one square centimeter in area. It was found that the spark preferred to jump through five centimeters of air to passing through the sulphate of copper. The entire range of my experiments precludes to my mind the idea that this effect is due entirely to polarization of the electrodes. The air evidently breaks down with increasing readiness when the electromotive force is increased beyond a certain limit. This is true also of liquid dielectrics like oil. One of the most striking experiments in this connection can be performed by coating a board with a thin layer of plumbago, which is polished upon the surface in such a manner as to make a resistance of about one thousand ohms between broad terminal bands of copper. When a discharge under a difference of potential of one million volts passes between the terminal bands which rest on the coated surface, the entire surface is luminous. If an orange is interposed between terminals of the apparatus which gives over two million volts, it glows in the dark like a golden Chinese lantern, and the discharge passes beneath the rind and over the liquid portion of the conductor. These experiments make it clear to my mind that the disruptive effects of lightning in rending trees and shattering structures is due in large measure to the expansion of confined air or to the sudden formation of steam produced by the electric spark preferring to break down the air to overcoming the resistance of the poor solid conductor.

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* These Proceedings, XXXII. 253.

The effects in air of a voltage of three million are extremely suggestive of the great energy in ordinary flashes of lightning. This voltage will produce sparks six to seven feet in length in ordinary air between small spheres. These discharges closely resemble lightning discharges. They can be obtained of nearly three feet in length from one terminal of the machine, the other terminal being insulated, by bringing near this terminal a conductor which is connected with the ground. It is evident that the electrical circuit is completed through the air to the insulated terminal. When the apparatus for discharging the Leyden jars or Franklin plates was first set up, the coated surfaces of these plates were not more than a foot from the floor. It was speedily discovered, when the room was darkened, that there was a powerful brush discharge to the floor. The entire apparatus was then lifted three feet. In this case there was a gain in the length of discharge which could be obtained; for the air resistance was thus increased. The apparatus is now peculiarly well situated, being three feet above the floor and at a distance from the walls of the room. When, however, the discharge takes place, one feels as if a window had been suddenly lifted, letting in a gust of wind, one's coat lifts, and sparks can be drawn from the neighboring walls. In order to get the full effect of such a voltage in producing discharges, the apparatus should evidently be placed thirty or forty feet above the earth, and should be remote from other masses.

Photographs of these powerful discharges closely resemble those taken of lightning. It is evident to my mind that many of the peculiarities of lightning flashes are due to imperfection in lenses, or to a want of focus. The so called ribbon discharge can be closely imitated by putting the camera out of focus. When a portrait lens of large aperture is employed, many details are obtained which are not shown by the ordinary landscape lens. Thus Plate III., taken by a Dallmeyer portrait lens, represents a single discharge from a sphere one foot in diameter to a long linear conductor which formed the positive terminal. The main discharge was between four and five feet long, and the air between the terminals was filled with a powerful brush discharge, which passed off at right angles to the surfaces. The portrait lens also shows that a single discharge is really made up of to and fro oscillatory discharges; for bifurcations are seen pointing in opposite directions on the line of discharge.

The effect of the high electromotive force which can produce such powerful discharges in air is also of great interest when it is examined in rarefied gases. The spectrum of hydrogen does not appear to be materially changed from the well known form obtained by interposing a Leyden jar in circuit with an ordinary Ruhmkorf coil. The four most prominent lines are present. Further investigation will be necessary to determine whether more lines are brought out by the increased electromotive force. The spectrum is exceedingly brilliant.

In a previous paper it has been pointed out that the instantaneous development of heat in disruptive discharges through hydrogen when the peculiar spectrum observable in stars is obtained is very great.* This spectrum is seen in the solar prominences, and therefore indicates a very high temperature, apparently much higher than the surface of the sun, which shows the fluted spectrum of carbon which can be produced in the electric furnace. This high temperature might be due to explosions of gas from the body of the sun, or it might be possibly caused by electric discharges through the masses of gas thrown up by some explosive action. The long continuance, however, of this spectrum of hydrogen indicates a prolongation of the state of high temperature. Electrical discharges occurring oftener than sixteen times a second might produce the spectrum and still account for the apparent high continuous state of temperature of the gas.

Leaving, however, for the present a more careful study of the hydrogen spectrum under the conditions of extremely high electromotive force, I pass on to the effects produced by such voltage in very highly rarefied media such as are contained in Crookes tubes. In these experiments I have been greatly assisted by Mr. John E. Burbank, graduate student.

The experiments were conducted with Crookes tubes containing no interval between the anode and the cathode; and no discharge therefore, in the usual sense, occurred in the tubes. A continuous conductor was led through the rarefied tube, and it was discovered that the X-rays were given off from every element of this conductor at right angles to its surface when a disruptive discharge occurred in the circuit of which the tube formed a part. This remarkable result was obtained by means of the very high electromotive force obtained by the apparatus represented in Plate I., which was charged by ten thousand storage cells.

The first tube is shown in Figure 1. It consisted of a straight wire tube joined to an ordinary Crookes tube of the focus pattern. This latter tube was joined to the straight wire tube in order to test the vacuum in the latter, and to be sure that the necessary conditions existed for the production of the X-rays. When the terminals of the straight wire tube were connected to the Planté machine, and the latter was excited, the entire tube fluoresced brilliantly. This fluorescence was especially bright in the connecting tube between the straight wire tube and the Crookes tube, and a beam of light passed across the Crookes tube and formed a fluorescent spot on its bulb.

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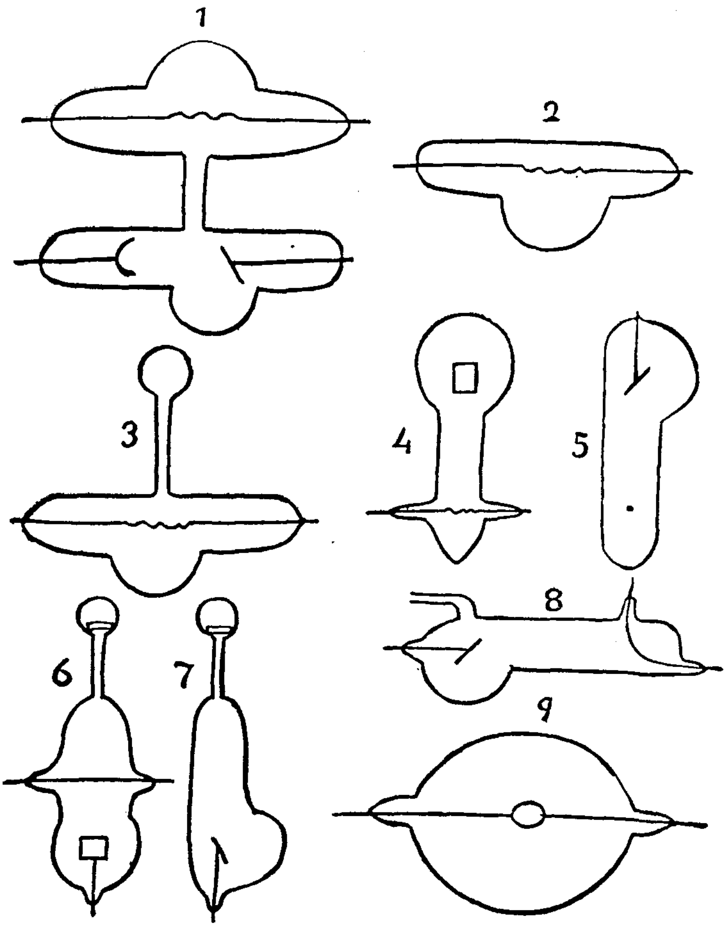
* Am. Journal of Science, Vol. III., April, 1897.



Figures 1 to 9.

Photographic plates were exposed opposite to the thin bulb on the straight wire tube. These plates were carefully insulated from the ground, and were covered in one case with a sheet of hard rubber an eighth of an inch in thickness, and in another case by a sheet of glass about half an inch in thickness. A powerful brush discharge was seen in the dark room to pass from the thin bulb of the tube to the insulator which covered the plates, and on developing the plates they were found to be covered with star-like clusters surrounded by nebulous patches. It was evident that the brush discharge had produced discharges at the surface of the dry plate, even through plates of glass half an inch in thickness. Moreover there was a general darkening of the surface of the plate which indicated the action of the X-rays. No metallic objects could be placed upon the dry plates, for a powerful spark immediately passed to them and punctured the tubes. The darkening, however, was apparently diminished under strips of glass, although the effect of the brush discharge masked the effect of the X-rays.

Before the straight tube was exhausted powerful brush discharges were given off at the ends of the tube. When the tube was exhausted these brushes were much diminished and were replaced by a powerful brush, which came off from the straight wire through the bulb of the tube and speedily punctured the latter when any object, even an insulator, was brought within six inches of the bulb. The most interesting result obtained with this form of tube was the production of the so called X-ray burn by means of the brush discharge from its bulb. When the back of the hand was exposed to this brush discharge, which assumed a peculiar forked nature in the dark room, a peculiar prickling sensation was experienced, and all the symptoms of the well known X-ray burn developed. The skin when examined under a microscope exhibited an appearance similar to that shown by the photographic plate. There were centres of inflammation surrounded by regions of lesser degrees of burn. It seems evident that the so called X-ray burn is due to an electrification, — a discharge at the surface of the skin, — and this electrification may or may not be accompanied by the X-rays. The first form of tube was then abandoned, and a straight wire tube alone (Fig. 2) was employed. Similar results were obtained with this tube. It was significant that the whole interior of this tube fluoresced brilliantly when it formed part of a circuit through which a disruptive discharge passed. This latter form of tube was replaced by that represented in Figure 3. A side ending in a thin bulb was added to the straight wire tube. The same phenomenon was exhibited by this tube: in addition, a brilliant fluorescence filled the side tube, which appeared to flow in or flow out of the narrow tube which ended in the small bulb. One is reminded by this phenomenon of Poynting's hypothesis of the flow of energy into a wire. This form of tube was replaced by a straight wire tube which is represented in Figure 4 and Figure 5 (side view). A straight wire passed completely through the tube, and was in circuit with a line on which there was a rapid change of potential. At one end of this tube opposite a thin bulb blown on the tube is a piece of platinum foil inclined like the ordinary focus plane in a focus tube. At first we connected this focus plane with the ground, and, having ascertained that X-rays were given off very strongly from this foil, we removed the ground connection and substituted for it a sheet of zinc. The tube still gave off X-rays. We then removed the sheet of zinc, and found that X-rays were given off with undiminished strength. This tube was then modified into the form represented in Figure 6 and Figure 7 (side view). The straight wire occupied the middle of a tube: in one end of this tube was placed a focus plane of platinum, and at the other end there was a long narrow tube which ended in a thin bulb. In this bulb was a crystal of calcite which was confined in the bulb by the narrowness of the bore of the connecting tube. This tube showed that X-rays were given off at right angles to the straight wire, for the calcite fluoresced a brilliant red and the fluoroscope showed X-rays proceeding from the inclined piece of platinum. This form of tube, moreover, showed that the X-rays are reflected, so to speak, from the interior surface of the glass, for there were multiple shadows of the wire on the sides of the tube which were produced by the X-rays of varying intensity that were developed on the surface of the glass, and which in turn, proceeding from this surface at different angles, produced elongated shadows. In the next form of tube, the wire passing through the tube was no longer straight, but was bent in the manner represented in Figure 8. In this form of tube there was a brilliant caustic formed on the sides of the tube opposite the concave side of the wire, and this brilliant caustic threw distorted shadows of the bent wire on the opposite side of the tube. It was evident that the X-rays were given off at right angles to the surface of this wire, and therefore coincided in direction with the lines of electrostatic force. We next experimented with the form of tube represented in Figure 9. This consisted of a large thin bulb five inches in diameter, enclosing a continuous conductor, the centre of which consisted of an aluminium mirror. When this tube was exhausted to a very high degree, the mirror formed a bright fluorescent spot on the bulb, the position of which could be readily changed by means of a magnet. When the exhaustion was carried to a very high degree, reversing the current from a Ruhmkorf coil through the tube caused no marked difference in the appearances in the tube; at a lower degree, however, a marked difference resulted.

With the employment of a powerful Ruhmkorf coil giving sparks of at least eight inches, X-rays could be detected in this tube, and when the tube was connected with the Planté machine, the X-rays gave strong effects in the fluoroscope.

In order to test the question whether the so called cathode rays and X-rays are generated primarily only at the cathode, a very large resistance of distilled water was interposed in the circuit with the continuous wire tube (Fig. 9) in order to damp any oscillations which might arise. The circuit thus consisted of the tube, the water resistance, a spark gap, and the secondary coil of a large Ruhmkorf. The tube was connected at first permanently to the air pump. As the exhaustion proceeded a beam of rays proceeded from the mirror on the continuous conductor which was focused on the wall of the tube. This beam was more brilliant and produced a stronger fluorescence on the tube when the wire was negative than when it was positive. At a higher stage of the vacuum, however, very little if any difference could be detected in the appearance of the tube, and X-rays could be detected outside the tube opposite the fluorescent spot caused by the mirror. That is, the X-rays were given off when the wire constituted both the cathode of the circuit and also the anode. It seems, therefore, that the term cathode rays is not a general one. It would seem that electric rays might be a more comprehensive one for both cathode rays and X-rays.

Furthermore the phenomenon of electrostatic induction plays an important part in the phenomena of the so called X-rays. When the tube represented in Figure 9 had reached a certain stage of exhaustion, a bit of tin-foil connected to a zinc plate 10 by 16 cm. and 1 cm. thick, was stuck upon the outside of the tube where the mirror formed the fluorescent spot. This zinc plate was carefully insulated from the ground. It was seen that a bundle of rays was reflected by the tin-foil to the opposite wall of the tube, showing a well defined shadow of the mirror and the continuous conductor on this wall. The direction of this shadow could be changed at will by changing the position of the tin-foil. This phenomenon was produced both when the wire was the cathode and when it was the anode. It can be explained on the hypothesis that a layer of electrified particles is held by a condenser action on the wall of the tube, and that the fresh coming particles are strongly repelled by those that have accumulated at the spot.

The behavior of aluminium toward the X-rays is so remarkable that it merits especial investigation. Can it be that it manifests a remarkable condenser action toward the high electromotive forces which produce the X-rays, similar to the action which has been observed at lower voltages?[*] We connected to the air pump, at the same time, two exactly similar tubes, one of which had two pointed terminals of platinum, the other two pointed terminals also; but one consisted of aluminium and the other of platinum. The discharge from a Ruhmkorf coil was sent through these tubes, which were in multiple circuit. At a certain stage of the exhaustion it was seen that the discharge passed more easily when the aluminium wire was made a cathode than when it constituted the anode. When the wire terminals in both tubes were made of thin disks, the difference was less marked. This might have been surmised, from previous investigations on the effect of form of electrodes on resulting polarization.[†] It may be that the anomalous action of aluminium in respect to X-rays is due to a species of dielectric polarization on the surface of the platinum, and that thus the surface becomes a new source of electrostatic stress, similar to that which was observed by connecting a bit of tin-foil and a capacity with the tube. Since we are dealing with very high differences of potential and with high charges on the ions, the instantaneous exhibition of electrical energy is very great, and might probably explain the diffusion of this energy through the air. According to this hypothesis the light manifestations of the X-rays arise only at the fluorescent screens, or at other suitable surfaces.

In continuing these studies of the electrical discharge in a vacuum, one is naturally led to examine the breaking down of the resistance of rarefied spaces by means of the X-rays which has been noticed by many physicists. The form of tube employed in the first experiment is shown in Figure 10, in which K is the cathode, A the anti-cathode, and C the gap between two terminals connected through a galvanometer with a battery. At the X-ray vacuum the smallest voltage which could set up a current when the gap C was illuminated by the X-rays was 240 volts. In the next form of tube which was employed (Fig. 11), the gap C was replaced by the gaps GG' placed on opposite sides of the anti-cathode and very near it. The breaking down effect was strong in this form of tube; and the residual effect of the X-rays was very marked after they had ceased to be excited. For instance, if the battery current would just pass when the X-rays were illuminating the tube, it would also flow some seconds after the cessation of the X-rays, showing the residual effect of these rays. In order to form an estimate of the resistance offered to disruptive discharges by the X-ray vacuum, the resistance of the X-ray tube was measured in the process of pumping when it had reached a pressure of 2 mm., at which stage the rarefied air appears to have the greatest conductibility, and it was next measured at the X-ray vacuum, the gap *C* being illuminated by the X-rays. These measures of resistance were made by using an additional air gap in the circuit, and by the method of dampening of oscillations. Nine oscillations could be obtained through the rarefied air at 2 mm. pressure, while under the same conditions eleven oscillations were obtained in the X-ray vacuum. This shows that, when this high vacuum is broken down, it exhibits less resistance than air at 2 mm. pressure.

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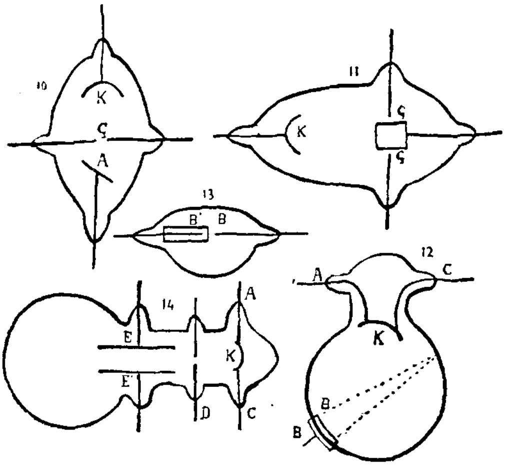
[*] L. Graetz, Wied. Ann., No. 10, 1897, p. 323.

[†] Karl Robert Klein, Wied. Ann., No. 10, 1897, p. 259.



FIGURES 10 TO 14.

In another experiment the gap *C* was placed in a tube which was separate from that in which the X-rays were produced, in order to prevent any disturbing effect of the current which produced the X-rays. The same breaking down effects were observed, although they were lessened by the necessary weakening of the X-rays, since they had to pass through two surfaces of glass separated by a layer of air.

In order to confirm the statement that this breaking down effect is exerted at the cathode in the tube through which a battery current is led, one of the terminals was covered with a piece of thick barometer tubing which projected beyond the metal of the terminal *B'* (Fig. 13). This thick glass served to diminish the effect of the X-rays on this terminal. By reversing the terminals it was then found that the breaking down effect was exerted principally upon the negative terminal.

Since these investigations had shown that there are anode rays as well as cathode rays, it was of interest to investigate the breaking down effect of the anode rays. The form of tube was similar to those before described, being provided with a continuous conductor, which could be made positive or negative at will; and it was found that the breaking down effect was manifested also by the anode rays.

With the tube represented in Figure 11, it was discovered that a difference of potential of 10,000 volts between *GG′* could produce the X-rays, and indications of them could be obtained at 2,500 volts; and it may be that they exist even in discharges produced at a less voltage; and is it not possible that they may be the initial cause of the breaking down of even atmospheric air, by setting up lines of polarization or stress?

The conviction has been expressed that electrostatic induction plays an important part in the production of the X-rays, and the following additional experiments were undertaken with a modified form of tube. The first experimental tube was constructed as follows. A continuous conductor *A K C* (Fig. 12) was enclosed in a Crookes tube. One portion of this conductor consisted of an aluminium mirror, *K*. The wires leading to *K* were covered with glass tubing, and the metallic surface of the back of *K* was coated with an insulating glaze. The X-rays produced when *K* was made the anode or cathode could be diverted in any direction by means of a piece of tin-foil placed on the outside of the bulb and connected with a suitable capacity, which was carefully insulated. A metallic concave disk was then enclosed in the bulb. This disk, being entirely disconnected from the continuous conductor *A K C*, could be moved into any position by suitably inclining the tube. The disk *B′* served to generate by induction a new beam of rays, which was much intensified by placing a disk of tin-foil on the outside of the glass opposite the disk inside the bulb and connecting this tin-foil with an insulated piece of metal.

The material of the enclosed disk did not appear to influence the result. In one case it was made of lead, and in another of aluminium. It was not necessary that the inner disk should be at the focus of *K*. A number of such disks could doubtless be employed, all of which would manifest such inductive action.

In order to see if we could detect any refraction of the lines of electrostatic force, a disk of paraffine having the same radius of curvature as the outside of the glass bulb was placed at a certain position on the bulb, and a piece of tin-foil was then placed on the outer surface of this disk *B* of paraffine and connected with a suitable insulated capacity. In this case the fluorescent spot produced by electrostatic action was spread out and ill defined, much as if a disk of glass of similar form should be placed in the path of rays of light coming from a concave mirror.

It therefore seems to us that in the generation of the X-rays the electrostatic lines of induction are suddenly formed together with currents of displacement, and that the wave front quickly advances, probably with the velocity of light, and that the molecular effects observed are merely the concomitants of the electromagnetic disturbances.

Since the production of the anode rays requires a higher vacuum than that at which the cathode rays are excited, we were interested to ascertain if the molecules of the gas under their influence possessed a greater or less velocity than that already found for particles moving from the cathode. We accordingly constructed a tube which was substantially similar to that employed by Prof. J. J. Thomson in his investigation of the effect of the electrostatic field on the path of the molecules excited by the cathode ray.* The modifications consisted in the substitution of a continuous conductor *A K C*, Figure 14, for the cathode and anode of his tube. In the figure, *E* and *E′* represent plates maintained at a known potential, thus giving an electrostatic field, and *D* is a suitable diaphragm. We expected to obtain a greater or less deviation of the position of the fluorescent spot formed on the surface of the bulb by the anode rays emanating from *K*. The inductive effect, however, of the plates *E* and *E′* was so great when *K* was positive that no measures were possible. This form of tube thus exhibited still more strongly the effects of electrostatic induction, and confirmed us in the belief that electrostatic induction is an important phenomenon in the generation of the X-rays.

CONCLUSIONS.

1. Beyond one million volts the initial resistance of atmospheric air to electrical discharges becomes less and less, and in certain conditions can be as low as one thousand ohms between terminals two or three inches apart. The curve therefore representing the relation between length of spark and electromotive force departs from a straight line beyond one million volts and approaches the axis which represents the increase of voltage. .

2. When the initial resistance of highly rarefied air is broken down by means of the X-rays, it exhibits less resistance than it does at the

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* Phil. Mag., October, 1897.

point of 2 mm. pressure, when it is generally considered of the greatest conductibility.

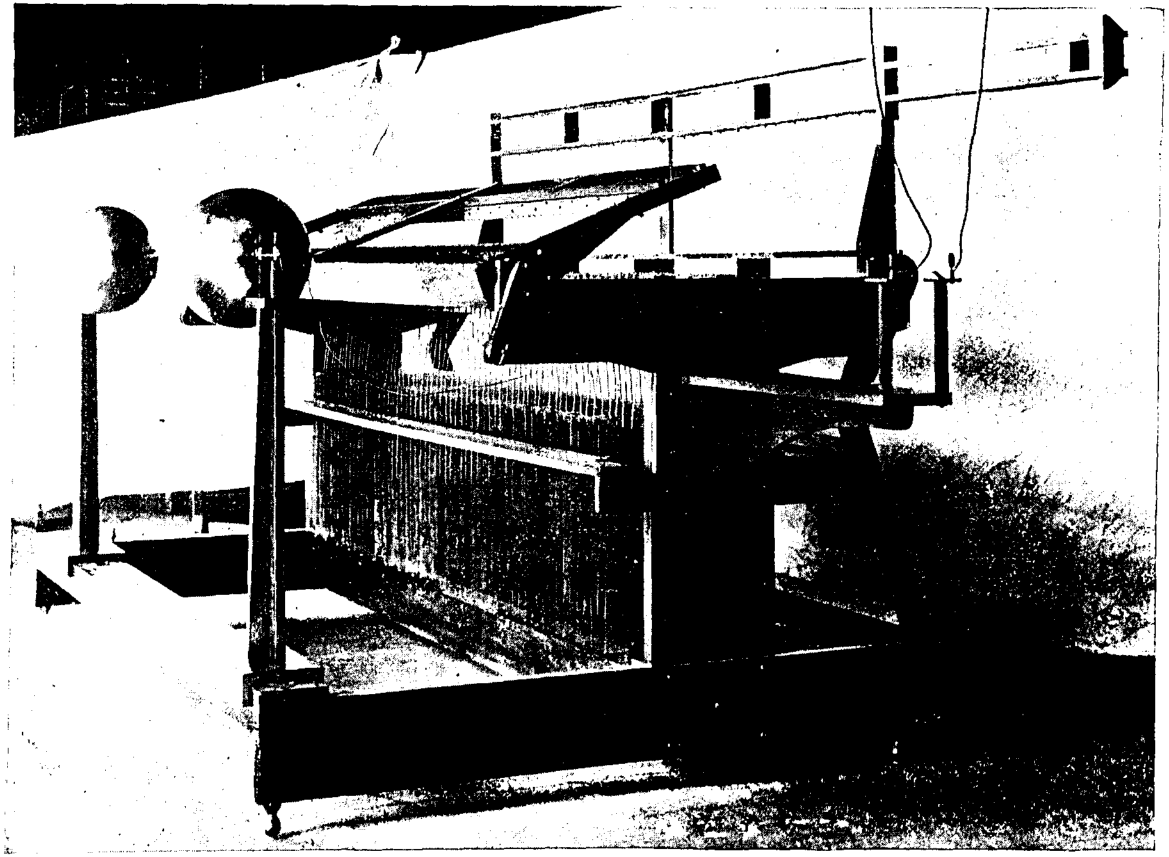
3. There are anode X-rays as well as cathode X-rays, and these rays exhibit all the peculiarities of the cathode rays; such as the excitation of fluorescence, phosphorescence, and the peculiar action of breaking down the initial resistance of air and other gases.

4. The X-rays can be distinctly produced with an electromotive force of 10,000 volts, and there are indications of them at a voltage of 5,000.

5. Electrostatic induction is an important phenomenon in that of X-rays. Experiments indicate that the X-rays are evidence of an electromagnetic disturbance, to which lines of electrostatic form are set up in the medium, and that the disturbance therefore travels with the velocity of light, and is accompanied by molecular excitation, which however is only one of the concomitants of the electromagnetic disturbance.

6. The mechanism, therefore, of the production of the X-rays appears to be a setting up of electrostatic lines of induction along which the electromotive force or difference of potential acts, and a production of an electromagnetic wave or impulse. The stress in the medium reduces its initial resistance, and the X-rays' radiation becomes less and less energetic after a certain interval the longer the Crookes tube is excited; for the increased conductibility of the medium persists after each pulse of such radiation, and therefore the difference of potential between the terminals speedily drops, or does not rise to the full value which the induction machine is capable of developing.

7. The behavior of highly rarefied media to powerful electric stress is analogous to that of elastic solids to mechanical stresses. A so called vacuum which acts like an insulator when submitted to an electromotive force capable of producing a spark of eight inches in air (approximately two hundred thousand volts) breaks down under the stress of three million volts. A single discharge with this voltage through highly rarefied media produces the X-rays in such a powerful manner that a photograph of the bones of the hand can be taken in one millionth of a second. During the discharge the apparent resistance of the rarefied medium is only a few ohms. In this case the medium seems completely to lose its elasticity so to speak, and is ruptured. The elastic solid analogy seems to explain the behavior of highly rarefied media toward powerful electric stresses. The generation of the X-rays is accompanied by a powerful electrostatic stress which breaks down the so called elasticity of the medium. The question of the electrical conductivity of the ether, it seems to me, can be studied best from the elastic solid point of view.



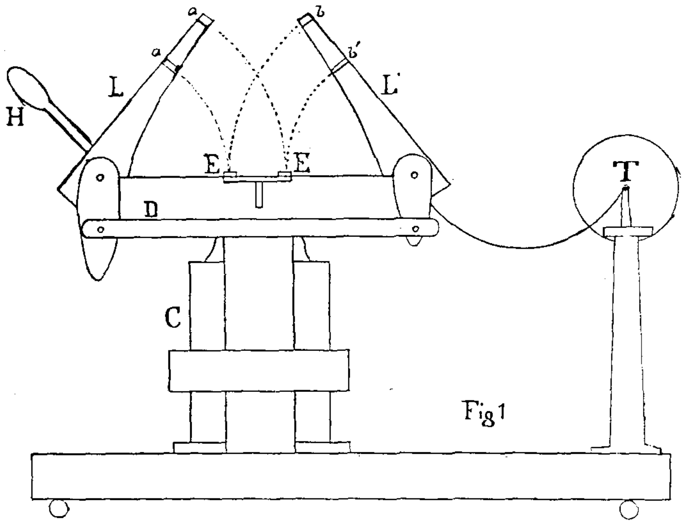

a
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Fig 1

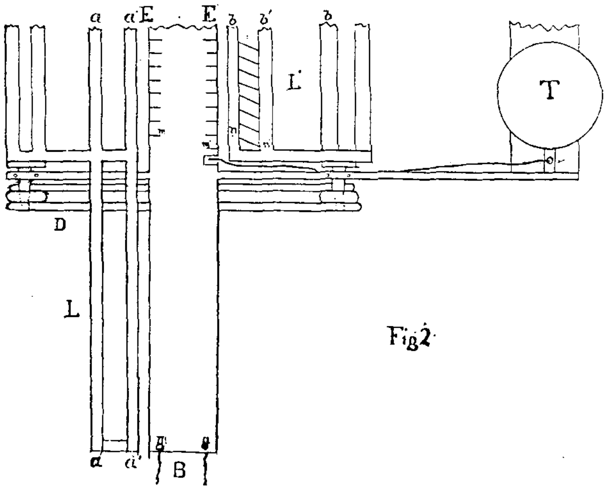
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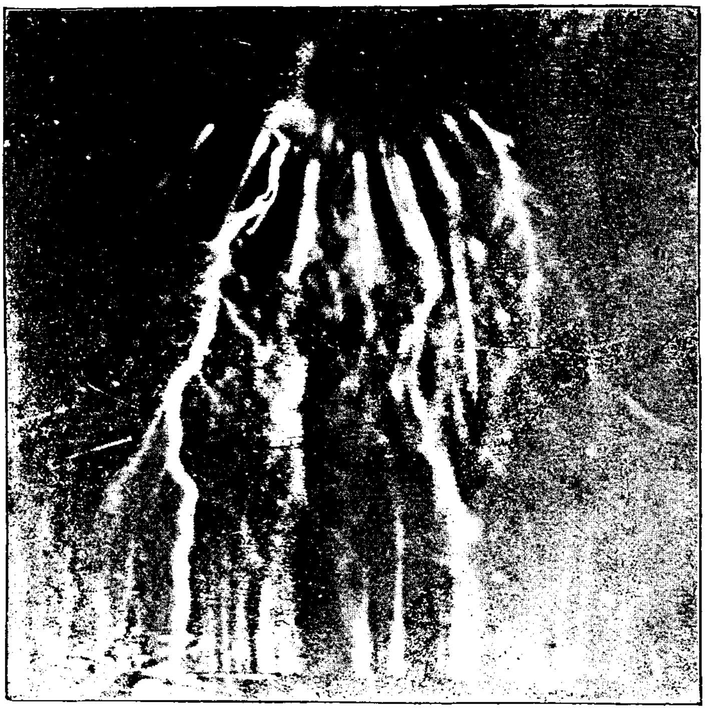
Fig 2



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CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY.

New Series. — No. XIV.

By J. M. Greenman.

I. Revision of the Mexican and Central American Species of *Galium* and *Relbunium*.

II. Diagnoses of New and Critical Mexican Phanerogams.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, No. XIV.

By J. M. Greenman.

Presented by B. L. Robinson, April 13, 1898.

I. — REVISION OF THE MEXICAN AND CENTRAL AMERICAN SPECIES OF GALIUM AND RELBUNIUM.

A preliminary study of the Mexican and Central American species of *Galium* has made it necessary to take into consideration the North American representatives of the nearly allied genus *Relbunium*. The latter, although not so numerously represented in Mexico, increases southward and attains its maximum in South America, where it to a considerable extent replaces the genus *Galium*.

Relbunium was first so designated by Endlicher,[1] as a section under *Galium*. Subsequently it was taken up by Bentham and Hooker,[2] and established as a genus; a similar view being held by Schumann[3] and by Hemsley,[4] while Dr. Gray in the Synoptical Flora placed the North American representatives of *Relbunium* under *Galium*.

The typical *Relbunium*, however, is so well marked by its involucrate flowers and distinctly axillary inflorescence, that it has seemed best to the writer in the following synoptic revision to follow essentially the generic limitations laid down by Bentham and Hooker, and by Schumann in Engler and Prantl's Nat. Pflanzenfamilien.

It may be added that in the examination of a large number of specimens no difficulty whatever was experienced in placing a given specimen definitely either in one genus or in the other, except in the case of *G. angulosum*. This species is somewhat intermediate between the two genera, but a close examination of the inflorescence seems to indicate its affinity with *Galium* rather than with *Relbunium*.

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[1] Gen. Pl. 523.

[2] Gen. ii. 149.

[3] Fl. Bras. vi. pt. 6, 103; Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 4, 154.

[4] Biol. Cent.-Am. Bot. ii. 62.

It will be noticed that a few species are herein treated which have not as yet been reported from Mexico or Central America. In these cases the known locality is such that the occurrence of the species may be expected in Northern Mexico. Besides the material in the Gray Herbarium, the writer, through the kindness of Dr. J. N. Rose, has been permitted to borrow from the U. S. National Museum for examination the Mexican and Central American specimens of these two genera.

GALIUM, Linn. (Name from ancient Greek γάλιον, supposed to be *Galium verum*, and derived by Dioscorides from γάλα, milk, which it was used to curdle.) Flowers perfect, polygamo-diœcious, or unisexual, exinvolucrate. Calyx-tube ovoid or globose; limb obsolete. Corolla rotate, usually 4-lobed (not unfrequently 3-lobed, and rarely 5-lobed); lobes valvate. Stamens of the same number and alternating with the lobes of the corolla, adnate to the base of the tube: anthers on short filaments, exserted. Disk annular. Ovary 2-celled; styles more or less 2-cleft; stigmas capitate; ovules solitary in the cells, borne on the dissepiment, amphitropous. Fruit didymous, dry, subcarneous, or distinctly baccate, smooth, tuberculate, or hispid, separating into closed carpels, or only one carpel maturing. Seeds concave on the face; embryo curved; cotyledons foliaceous; radicle inferior. — Annuals, herbaceous perennials, or rarely suffruticose plants. Leaves in whorls of 3 to many. Flowers usually disposed in axillary or terminal cymes, occasionally simply axillary, or terminal, white, yellow, greenish, or purplish. — Gen. 24; Benth. & Hook. f. Gen. ii. 149; Gray, Syn. Fl. N. A. i. pt. 2, 35 (excl. § *Relbunium* in part); Schumann in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 4, 149. For generic synonyms, which relate chiefly to the Old World, see Hooker f. & Jackson, Index Kewensis, i. pt. 2, 991.

§ 1. Fruit uncinate-hispid, or granular-papillose.

* Leaves in whorls of six or eight (rarely of ten or more); the angles of the stem as well as the midrib and margins of the leaves usually retrorsely aculeolate-hispid, less frequently smoothish, or rarely (in *G. triflorum*) somewhat hirsute.

+- Stems smoothish, or rarely somewhat hirsute-pubescent.

G. TRIFLORUM, Michx. Herbaceous: stems more or less pubescent: leaves elliptic-lanceolate to narrowly oblong-lanceolate, cuspidate-acuminate, 1.5 to 4 or rarely 8 cm. long, 5 to 10 or rarely 15 mm. broad, usually covered on the upper surface near the margin with subappressed hispidulous hairs, often slightly hispid on the midrib, otherwise glabrous: inflorescence cymose, terminal, usually 3-flowered. — Fl. i. 80; Willd. Hort. Berol. t. 66; DC. Prodr. iv. 601; Torr. & Gray, Fl. ii. 23;

Gray, Syn. Fl. N. A. i. pt. 2, 39; Wiegand, Bull. Torr. Club, xxiv. 403. — Common in moist shady places; Southern Greenland and Alaska to the Gulf of Mexico.

This species is doubtfully attributed to Mexico by Hemsley, Biol. Cent.-Am. Bot. ii. 66, but no Mexican specimens have been seen by the writer.

+ + Angles of the stem as well as the margins and midrib of the leaves retrorsely aculeolate-hispid.

++ Fruit granular-papillose.

1. **G. asperrimum,** Gray. Stems ascending, 3 to 6 dm. high, diffusely branched: leaves usually in whorls of six, oblanceolate, 1 to 2 cm. long, 3 to 6 mm. broad, glabrous except on the margins and midvein beneath: inflorescence cymose-paniculate, cymes dichotomously or trichotomously branching: flowers whitish: fruit about 2 mm. in diameter. — Pl. Fendl. 60, in Brew. & Wats. Bot. Calif. i. 284, & Syn. Fl. N. A. i. pt. 2, 39; Wats. Bot. King Exp. 134; Rothrock in Wheeler, Rep. vi. 138. — New Mexico, *Fendler*, no. 289; Sonora, *Wright*, no. 114; Chihuahua, hills west of the city of Chihuahua, *Pringle*, no. 558; also by the same collector on cool talus of cliffs, on neighboring mountains, no. 740; southwestern Chihuahua, August to November, 1885, *Palmer*, no. 414.

++ ++ Fruit more or less distinctly uncinate-hispid.

2. **G. aparine,** L. Stems 2 to 10 dm. or more long, somewhat reclining; nodes 2 to 10 cm. distant: leaves oblanceolate or oblanceolate-linear, 1 to 4 cm. long, 2 to 6 mm. broad, cuspidate-acuminate, usually hirsute-pubescent on the upper surface: flowers 1 to 3 in the upper axils, or terminating the lateral branches in 2–3-flowered cymes; corolla small, whitish: fruit 2 to 5 mm. in breadth. — Spec. i. 108; Reichenb. Ic. Fl. Germ. xvii. t. 1197; Gray, Syn. Fl. N. A. i. pt. 2, 36. — Sonora, *Thurber*, no. 437; Lower California, Guadalupe Island, *Palmer*, nos. 35, 850, All Saints' Bay, April, 1882, *Miss F. E. Fish.* — To the var. *Vaillantii*, Koch, Fl. Germ. ed. 1, 330 (Vaill. Par. t. 4, f. 4), some of the specimens above cited may be equally well referred. The variety differs only in being more slender, but as direct transitions occur no satisfactory distinctions can be drawn separating the variety from the species.

3. **G. mexicanum,** HBK. Stems ascending, much branched, strongly aculeolate-hispid on the angles, hirsute-pubescent at the nodes: leaves usually in sixes or eights, sometimes in whorls of ten or more, 8 to 20 mm. long, 1 to 3 mm. broad, margin revolute, apex strongly cuspidate-acuminate, usually smooth and shining above, rarely somewhat

hirtellous: inflorescence cymose-paniculate: corolla white or purplish, campanulate; lobes revolute, externally pubescent: fruit covered with rather short uncinate-hispid bristles. — Nov. Gen. & Spec. iii. 337; Hemsl. Biol. Cent.-Am. Bot. ii. 65. — Guanajuato, *Dugès;* Valley of Mexico, *Pringle*, no. 6518; Jalisco, Rio Blanco, *Palmer* (collection of 1886), no. 753; Tepic, near Santa Teresa, *Rose*, no. 2151; Orizaba, *Seaton*, no. 127. A specimen from Culiacan, *Palmer* (collection of 1891), no. 2777, may be doubtfully referred here.

Var. glabratum. Nearly glabrous throughout, otherwise as in the typical form. — Collected by *E. W. Nelson* on the west slope of Mt. Zempoaltepec, Oaxaca, altitude 2370 to 2460 m., 5 to 13 July, 1894, no. 583.

Var. platyphyllum. Similar to the species proper, but with broader oblanceolate or oblong-spatulate leaves, 1 to 2 cm. long, 2 to 6 mm. wide, abruptly cuspidate-acuminate at the rounded summit, not unfrequently hirtellous-puberulent beneath and occasionally hirsutish above. — Chiapas, near Christobal, altitude 2150 to 2704 m., 18 September, 1895, *E. W. Nelson*, nos. 3165, 3200; Oaxaca, Sierra de San Felipe, altitude 3075 m., 28 June, 1894, *Pringle*, no. 5663; vicinity of Yolontepec, altitude 1700 to 2150, 15 to 20 July, 1894, *Nelson*, no. 714; Colima, 9 January to 6 February, 1891, *Palmer*, no. 1407.

* * Leaves in whorls of four: the angles of the stem aculeolate-hispidulous: flowers cymose.

4. G. prætermissum, Greenm. Stems slender, 3 to 4 dm. long, ascending from a perennial base, slightly hispidulous: leaves linear-lanceolate to linear, 8 to 14 mm. long, 1 to 3 mm. broad, acute, margins revolute, upper surface often slightly hispidulous, the lower glabrous: flowers terminating the lateral branches in subtrichotomous cymes. — Proc. Am. Acad. xxxii. 306. — Federal District, *Pringle*, no. 6596.

* * * Leaves in fours: hirsute-pubescent to nearly glabrous plants, not retrorsely aculeolate-hispid: flowers terminating the stems and branches in rather close, or dichotomously branching cymes.

+ Flowers paniculately disposed in dichotomously branching leafy cymes: uncinate bristles of the fruit subappressed.

5. G. Pringlei. Stems 3 to 5 dm. high, erect or ascending from a perennial base, covered with a spreading hirsute pubescence: leaves in fours, the uppermost opposite, 1-nerved, oblong-elliptic to oblong-lanceolate, 4 to 12 mm. long, 1 to 5 mm. broad, submucronate, narrowed at the base, hirsute-pubescent upon either surface: flowers sessile or short-pedicelled: corolla whitish: fruit about 1.5 mm. in breadth, covered with subappressed uncinate hairs. — Collected by *C. G. Pringle* on shaded ledges of the Sierra Madre near Monterey, State of Nuevo Leon, 9 July, 1898, no. 1884, distributed as "*Galium uncinulatum*, DC.?"

+ + Flowers in terminal or lateral few-several-flowered loose cymes: uncinate bristles of the fruit spreading.

6. **G. orizabense**, Hemsl. An herbaceous perennial: stems 3 to 10 dm. or more long, erect or ascending, hirtellous-pubescent especially on the angles with short recurved hairs: leaves obscurely 3-nerved, linear-lanceolate or linear-oblong, 0.5 to 2 cm. long, 1.5 to 5 mm. wide, obtuse, a little narrowed at the base, usually hirtellous-pubescent upon either surface, and especially on the midrib beneath. — Diag. Pl. Nov. pars tertia, 54, & Biol. Cent.-Am. Bot. ii. 65. — Region of Orizaba, *Sumichrast*, nos. 838, 1933; *Müller*, nos. 1144, 1326; *Botteri*, no. 538.

7. **G. uncinulatum**, DC. Stems slender, usually several from a perennial base, nearly glabrous or pubescent with spreading or somewhat reflexed hirsute hairs: leaves 3-nerved from the subpetiolate base, oblong to oblong-lanceolate, mucronate, more or less hirsute upon either surface, especially on the veins beneath, sometimes nearly glabrous: inflorescence terminating the lateral branches in three–few-flowered cymes. — Prodr. iv. 600; Hemsl. Biol. Cent.-Am. Bot. ii. 66; Wats. Proc. Am. Acad. xviii. 99. *G. Jalapense*, Schlecht. Linnæa, ix. 591. — Sonora, *F. E. Lloyd*, no. 393; Nuevo Leon, Guajuco, *Palmer*, March, 1880, no. 412; San Luis Potosi, *Schaffner*, no. 840 (a nearly smooth form); Valley of Mexico, *Schaffner*, no. 179, *Pringle*, no. 6462; Orizaba, *Botteri*, nos. 188, 945, 1174, *Müller*, no. 1820, *Seaton*, no. 209, *Sumichrast*, no. 1921; Oaxaca, vicinity of Cerro San Felipe, *Nelson*, no. 1103. Specimens collected by Pringle, San Luis Potosi, no. 5125, and Puebla, no. 7018, seem to connect with the following variety.

Var. **obstipum**, Wats. Leaves usually smaller, suborbicular to oblanceolate, densely hirsute-pubescent beneath. — Proc. Am. Acad. xviii. 99. *G. obstipum*, and varieties, Schlecht. Linnæa, ix. 592; Hemsl. Biol. Cent.-Am. Bot. ii. 65. — Coahuila, Lerios, about 70 km. east of Saltillo, July, 1880, *Palmer*, no. 413, by the same collector in the Caracol Mts., 33 km. east of Monclova, August, 1880, no. 414; Michoacan, Patzcuaro hills, 8 November, 1890, *Pringle*, no. 3597; Real del Monte, *Th. Coulter*, no. 185; Chiapas. *Ghiesbreght*, no. 886; Guatemala, Coban, Depart. Alta Verapaz, altitude 1325 m., *von Tuerckheim* (Donnell Smith's sets, no. 1222).

Var. (?) **nanum**. Low, about 1 dm. high: stems glabrous or slightly pubescent at the nodes: leaves oblanceolate, 5 to 10 mm. long, 2 to 3.5 mm. broad, submucronate, narrowed into a subpetiolate base, glabrous or somewhat hirtellous on the upper surface and on the margin, rather densely elongate-punctate: flowers terminating the lateral branches usually in 3-flowered cymes. — Collected about Orizaba by *Müller* in 1885, no. 1523.

+ + + Flowers terminating the stems and branches in small close cymes: uncinate bristles of the fruit spreading.

++ Essentially glabrous: flowers usually white or greenish white.

8. **G. Seatonii.** Perennial: stems prostrate or ascending, much branched, glabrous: leaves sessile, broadly oblong to oblong-lanceolate, 3 to 10 mm. long, 1.5 to 5 mm. broad, submucronate or short-acuminate, glabrous or slightly hirtellous on the upper surface: corolla about 3 mm. broad, 4-lobed; lobes oblong-ovate, acute: pedicels later becoming somewhat elongated, 3 to 8 mm. in length: fruit 1.5 mm. in breadth. — Mt. Orizaba, altitude 3075 m., 5 August, 1891, *Henry E. Seaton*, no. 174, distributed as *G. uropetalum*, Hemsl.; Federal District, Serrania de Ajusco, altitude 3075 m., 6 September, 1896, *Pringle*, no. 6461, distributed as *G. Jalapense*, Schlecht.

++ ++ Hirsute-pubescent: flowers purplish.

9. **G. Nelsonii.** Perennial: stems ascending, 1 to 2 dm. in length, more or less branched, hirsute-pubescent upon the angles and also at the nodes: leaves sessile, ovate or slightly oblong-ovate, acute, usually hirsute-pubescent above and on the midrib beneath, margin ciliate: flowers, bracts, and upper leaves purplish: corolla about 3 mm. in diameter, 4-parted; lobes oblong-ovate, obtusish. — Summit of Mt. Zempoaltepec, Oaxaca, altitude 3480 m., 9 July, 1894, *E. W. Nelson*, no. 628.

* * * * Leaves in fours: inflorescence chiefly axillary.

+ Flowers on slender pedicels.

G. TEXENSE, Gray. Annual, branching from the base: stems more or less erect, 1 to 3 or 4 dm. high, hirsute-pubescent: leaves ovate or oblong-ovate, 0.5 to 1.5 cm. long, one half to two thirds as broad, hirsute-pubescent upon either surface: peduncles axillary, slender, about equalling the leaves, occasionally proliferous: fruit 2 mm. in diameter. — Proc. Am. Acad. xix. 80, & Syn. Fl. N. A. i. pt. 2, 36. *G. Californicum*, var. *Texanum*, Torr. & Gray, Fl. ii. 20. *G. uncinulatum*, Gray, Pl. Lindh. ii. 215? not DC. — Texas, *Drummond*, no. 115, *Lindheimer*, no. 619, *Wright* (without number), on rocky hills near Austin, *E. Hall*, no. 274, along Brazos River, Palo Pinto Co., *Reverchon*. No specimens from Mexico, belonging to this species, have been seen by the writer, yet it is altogether probable that the species occurs south of the Rio Grande.

G. CANESCENS, HBK. Stems procumbent, nearly glabrous below, spreading-villous above: leaves ovate, 8 to 10 mm. long, 4 to 5 mm. broad, short-acuminate, 3-nerved, membranous, spreading-villous upon either surface, and upon the midrib beneath, ciliate, later somewhat glabrate: flowers axillary, solitary or terminating the branches in threes: corolla glabrous; lobes ovate, subacuminate. — Nov. Gen. & Spec. iii. 336. No Mexican specimens of this species have been seen by the author. Ghiesbreght's no. 886 from Chiapas, referred by Hemsley, Biol. Cent.-Am. Bot. ii. 64, to the above species, is best referred, as pointed out by Dr. Watson, Proc. Am. Acad. xviii. 99, to *G. uncinulatum*, DC., var. *obstipum*. The above description is drawn from Jameson's specimen collected in the Andes of Ecuador in 1859, which corresponds well with the original description.

← ← Flowers sessile.

11. **G. proliferum**, GRAY. Annual, simple or branching from the base: stems ascending or erect, 1 to 4 dm. high, shortly hirsute-pubescent, or nearly glabrous: leaves ovate or oblong-ovate, the lowermost often broadly ovoid and subpetiolate, obtuse, spreading-hirsute upon either surface, often nearly or even quite glabrous: flowers sessile, terminating the rather short lateral subhorizontally spreading branches, the lateral branches often proliferous, bearing a second or even a third flower: corolla white, small: fruit about 3 mm. in breadth on extremely short recurved pedicels, subtended by two or four upturned leaf-like bracts. — Pl. Wright. ii. 67, & Syn. Fl. N. A. i. pt. 2, 37. *G. virgatum*, var. *diffusum*, Gray, Pl. Wright. i. 80. — New Mexico, *Wright*, nos. 1112 (type), 281; Texas, El Paso, *Dr. Dieffendorfer*, also collected in the same locality by *Vasey* in 1881; Arizona, hills near Tucson, 28 April, 1883, *Pringle*, no. 15, on the foothills of the Santa Rita Mountains, 13 May, 1884, *Pringle*, in part; Nuevo Leon, Guajuco, about 40 km. southeast of Monterey, March, 1880, *Palmer*, no. 411.

Var. **subnudum**. Stem and leaves glabrous: fruit only slightly hirtellous. — Foothills of the Santa Rita Mountains, Arizona, 13 May, 1884, *Pringle*, in part.

G. VIRGATUM, Nutt. Stems simple or branched from the base; branches spreading or erect, 1 to 3 dm. high, somewhat virgate, hirsute-pubescent upon the slightly thickened angles, occasionally nearly glabrous: leaves oblong-linear to oblong-lanceolate, 1 cm. or less in length, 1 to 3 mm. broad, obtusish, usually hirsutish above and on the midrib beneath, ciliate, sometimes nearly glabrous: flowers terminating the extremely short lateral branches or peduncles, appearing axillary, subtended by two leaf-like bracts, the lateral branches or peduncles not proliferous, reflexed in fruit. — Torr. & Gray, Fl. ii. 20; Gray, Pl. Lindh. ii. 215, & Syn. Fl. N. A. i. pt. 2, 36. *G. Texanum,* Scheele, Linnæa, xxi. 597. — Louisiana, *Hale;* Texas, *Lindheimer*, nos. 246, 491, *Drummond,* no. 111, *Wright* (without number), at Belknap, *Sutton Hayes*, no. 327 in part, Dallas, May, 1875, *Reverchon, Heller*, no. 1437 (distributed as *G. Texense,* A. Gray); Missouri, Allenton, 15 June, 1880, *Geo. W. Letterman;* Tennessee, cedar barrens at La Vergne, 16 May, 1882, *Gattinger.*

VAR. LEIOCARPUM, Torr. & Gray. Stem and leaves nearly glabrous: fruit smooth and glabrous. — Torr. & Gray, Fl. ii. 20; Gray, Syn. Fl. N. A. i. pt. 2, 36. — Texas, *Drummond,* no. 113, *E. Hall,* no. 273, *Wright* (without number), also a specimen of Nuttall's collection bearing the datum "Red River."

§ 2. Fruit hirsute with long and straight (not uncinate-tipped) bristles.

* Leaves linear or linear-oblong (in *G. Wrightii,* var. *latifolium,* often somewhat elliptic or oblong-oblanceolate), 1-nerved.

+ Flowers axillary, solitary or in pairs, subsessile.

12. G. oresbium. Perennial: stems from a woody base, somewhat cespitose, 1 to 2 dm. high, below often naked and glabrate, numerously branched, leafy and pilose-hirsute above: leaves in fours, linear or linear-oblong, 2 to 4 mm. long, 1 mm. or less in breadth, acutish, hirsute-pubescent, margin revolute, midrib much thickened and prominent beneath, bearing on the under surface near the apex a single large gland: corolla about 2.5 mm. in diameter, 4-parted; lobes oblong-ovate, obtuse, externally pubescent. — Collected by *C. G. Pringle,* on dry mountain walls, Sierra de la Silla, Nuevo Leon, 16 July, 1889, no. 2542.

+ + Inflorescence cymose-paniculate: flowers distinctly pedicellate.

++ Diœcious: flowers yellowish.

G. FENDLERI, Gray. Stems several, erect or ascending, 1.5 to 3 dm. high, rising from a perennial base, glabrous or minutely and closely puberulent: leaves linear or linear-oblong, 0.5 to 1.5 cm. long, 1 to 3 mm. broad, acute or obtuse, glabrous or finely puberulent: flowers small: ovary bearing inconspicuous closely appressed hairs, these later spreading and becoming more prominent. — Pl. Fendl. 60, & Syn. Fl. N. A. i. pt. 2, 41. *G. Rothrockii,* Gray, Proc. Am. Acad. xvii. 203, in part (as to Rusby's plant). — New Mexico, *Fendler,* no. 288, White Mts., altitude 2300 m., *Wooton,* no. 287; Arizona, Mogollon Mts., *Rusby,* no. 155, Santa Rita Mts., 10 July, 1881, and 25 July, 1884, *Pringle,* Mt. Graham, *Rothrock,* no. 416, near Fort Huachuca, *Lemmon,* no. 2903.

++ ++ Flowers perfect or polygamo-monœcious, purplish.

13. **G. Rothrockii,** Gray. Stems several from a woody base, profusely branched, hirtellous-pubescent below and on the young shoots, glabrous above, rarely glabrous throughout: leaves linear, 0.5 to 1.5 cm. long, rather rigid, acute or short-acuminate, subpungent-tipped, glabrous or somewhat hirtellous: lobes of corolla acuminate: fruit rather sparingly hirsute. — Proc. Am. Acad. xvii. 203 (excluding Rusby's plant), & Syn. Fl. N. A. i. pt. 2, 39. — Arizona, *Rothrock*, no. 675, *Lemmon*, nos. 526, 3010, 2718; Lower California, *Orcutt*, no. 912; Sonora, *Wright*, no. 1113 in part; Chihuahua, *Pringle*, no. 661.

14. **G. Wrightii,** Gray. Hirsute-pubescent throughout: stems about 3 dm. high, rising from a woody base, profusely branched above: leaves linear to linear-oblong, 0.5 to 1.5 cm. long, 1 to 3 mm. broad, obtusish to mucronate-acuminate: corolla brownish purple; lobes mucronate-acuminate: fruit more densely hirsute than in the preceding species. — Pl. Wright. i. 80, ii. 67 in part, & Syn. Fl. N. A. i. pt. 2, 39. — Arizona, Apache Pass, *Lemmon*, no. 615, near Fort Huachuca, nos. 2902, 3011–2; New Mexico, *Wright*, nos. 421, 235 (type); Sonora, *Wright*, no. 1113 in part.

Var. latifolium, Rob. & Fern. Much less pubescent than in the species proper: leaves linear-oblong to elliptic-oblong, slightly narrowed toward the base, 0.5 to 1.5 cm. long, 1 to 5 mm. broad. — Proc. Am. Acad. xxx. 116. — Sonora, *Hartman*, no. 58.

* * Leaves linear-lanceolate to ovate-acuminate, lateral nerves absent.

15. **G. stellatum,** Kellogg. Suffruticose, 2 to 6 dm. high: stems covered with a light gray or yellowish bark; branchlets hirtellous or hispidulous: leaves rather rigid, 0.5 to 1.5 cm. long, 1 to 5 mm. broad, usually attenuate-acuminate, sometimes ovate, merely acute: flowers white: fruit densely pilose-hirsute; hairs in length exceeding the diameter of the fruit. — Proc. Cal. Acad. ii. 97, f. 26; Gray, Syn. Fl. N. A. i. pt. 2, 40. *G. acutissimum*, Gray, Proc. Am. Acad. vii. 350, not of Eastwood, Proc. Cal. Acad. vi. 292 (1896). — "Between the Rio del Norte and New Mexico," *Dr. Newberry*; Southern Utah, Santa Clara, *Palmer*, no. 86; Arizona, Camp Grant, 27 April, 1867, *Palmer*, no. 105, rocky cañons of the Santa Catalina Mts., altitude 770 to 1085 m., 19 April, 1881, *Pringle*, Santa Cruz, *Parish*, no. 76, Wickenburg, *Palmer*, no. 616; Southern California, *Parish*, nos. 1724, 2381, Colorado Desert, San Diego Co., *Orcutt* (without number), Panamint Mountains, *Coville* & *Funston*, no. 715; Lower California, Los Angeles Bay, Gulf of California, November, 1887, *Palmer*, nos. 525, 525½, 526.

* * * Leaves elliptic to oblong-ovate, usually 3-nerved from the base, bearing a single large gland or cluster of glands on the lower surface at the tip.

+ Leaves distinctly 3-nerved, margins strongly revolute.

16. **G. hypadenium**, Schauer. Suffrutescent: stems prostrate or ascending, glabrescent, often leafless and little branched below, covered with a thin grayish bark which later separates from the stem, freely branching above; branches tetragonal, pilose-hirsute: leaves sessile, 4 to 10 mm. or more long, nearly one half as broad, obtuse, usually hirsute-pubescent, more or less glabrate above, rather densely white-pilose or merely hirsute beneath, margins ciliate: corolla 4-parted, about 2 mm. in diameter; lobes externally pubescent with rather long hairs: fruit about 2 mm. in breadth; carpels somewhat separated at maturity. — Linnæa, xx. 700. *G. leucotrichum*, Hemsley, Biol. Cent.-Am. Bot. ii. 65, & v. t. xli. figg. 4–6. — Orizaba, *Müller*, nos. 174, 1218, *Sumichrast*, no. 514; Puebla, dry limestone ledges near Tehuacan, altitude 1540 m., 27 August, 1897, *Pringle*, no. 6694; Guerrero, between Chilopa and Tixtla, altitude 1540 to 2150 m., 17 December, 1894, *E. W. Nelson*, no. 2166; Jalisco, near Guadalajara, *Pringle*, 5046.

17. **G. fuscum**, Mart. & Gal. Perennial: stems tetragonal, becoming more or less scabrous along the slightly thickened angles, the younger stems and branches bearing scattered pilose-hirtellous slightly curved hairs: leaves elliptic-oblong, 0.5 to 1.5 cm. long, 2 to 8 mm. broad, short-petiolate, submucronate or merely acute, glabrous or sparingly hirsute above and upon the nerves beneath, conspicuously glandular-punctate; margins usually ciliate: inflorescence cymose-paniculate: flowers brownish purple; lobes of corolla commonly pubescent. — Bull. Acad. Brux. xi. i. 126; Walp. Rep. vi. 13; Hemsley, Biol. Cent.-Am. Bot. ii. 64. — Oaxaca, Cerro de San Felipe, *Galeotti*, no. 2633, dry hills near the City of Oaxaca, altitude 1845 m., *Pringle*, no. 4795 (distributed as *G. uncinulatum*, DC., var. *abstipum*, Watson), near Reyes, altitude 1750 to 2000 m., *E. W. Nelson*, no. 1774; Guanajuato, *Dugès*.

+ + Leaves indistinctly 3-nerved, margins little or not at all revolute.

18. **G. hystricocarpum**. Stems usually many from a perennial base, ascending, more or less branched above, covered with a spreading pilose-hirsute pubescence: leaves elliptic-oblong to oblong-lanceolate, 5 to 12 mm. long, 2 to 7 mm. broad, short-acuminate or submucronate, hirsute on the upper surface and upon the midrib and inconspicuous lateral nerves beneath: flowers white, somewhat cymose-paniculate or terminating the lateral branches in few-flowered cymes: lobes of the corolla covered externally with a few long pilose hairs. — Cool cliffs and

ledges on mountains near Chihuahua, 25 October, 1886, *Pringle,* no. 741, distributed as *G. uncinulatum*, DC., var. *obstipum,* Watson.

§ 3. Fruit smooth and glabrous, dry, subcarneous or distinctly baccate.

* Herbaceous, nearly or quite glabrous plants: leaves usually in fours, occasionally in fives, sixes, or in whorls of seven.

+ Leaves linear-oblong to spatulate-oblong, obtuse: fruit dry.

G. Brandegei, Gray. Low herbs: stems 0.5 to 1.5 dm. high, usually matted or cespitose-depressed, glabrous or minutely hispidulous on the angles: leaves 5 to 10 mm. long, 2 to 3 mm. broad, glabrous or slightly hispidulous on the margins and midrib beneath: flowers axillary, solitary or in pairs: pedicels in fruit usually less than 1 cm. in length. —Proc. Am. Acad. xii. 58, & Syn. Fl. N. A. i. pt. 2, 38. *G. Brandegeei,* Wiegand, Bull. Torr. Bot. Club, xxiv. 398. — New Mexico, Valley of the Rio Grande, *Brandegee* (type); extending northward, according to Wiegand, to Saskatchawan. No Mexican specimens of this species have been seen by the writer, although the plant very probably occurs along the northern boundary.

19. **G. trifidum,** L., var. **subbiflorum,** Wiegand. Stems weak, ascending, usually much branched, nearly glabrous: leaves 5 to 15 mm. long, about 2 mm. broad, obtuse or slightly rounded at the apex, slightly hispidulous on the margins. — Bull. Torr. Bot. Club, xxiv. 399. — Federal District, Valley of Mexico, *Pringle,* nos. 6785, 7208.

Very difficult of separation, and perhaps not distinct from *G. Claytoni,* Michx.

+ + Leaves (nearly 4 cm. in length) oblong or obovate, cuspidate or aristate: fruit subcarneous.

20. **G. glaberrimum,** Hemsl. Glabrous throughout, glaucous; branches striate: leaves in whorls of seven (or the uppermost opposite), sessile, membranous, cuneate: flowers minute, disposed in a loose cyme; pedicels slender: fruit naked, somewhat fleshy. — Diag. Pl. Nov. pars tertia, p. 53, & Biol. Cent.-Am. Bot. ii. 64. — Mexico, *Liebmann,* no. 220.

+ + + Leaves (1.5 cm. or less in length) linear-oblong to elliptic-oblong, cuspidate-acuminate: fruit subcarneous or distinctly baccate.

++ Inflorescence terminating the stems and branches in few-flowered cymes: fruit subcarneous.

21. **G. Galeottianum,** Walp. Perennial nearly glabrous throughout, slightly hispid on the stems below: stems slender, reclining or ascending, 3 to 15 dm. long: leaves in fours, linear-oblong to oblong-

ovate, 5 to 10 mm. long, 1 to 4 mm. broad, acuminate, glabrous or slightly hispidulous on the margins, elongate-glandular-punctate beneath, and with a cluster of glands below near the tip: flowers brownish purple; lobes of the corolla cuspidate-attenuate. — Rep. vi. 17. *G. uropetalum*, Hemsley, Biol. Cent.-Am. Bot. ii. 66, & v. t. xli. f. 7–9. *Rubia acuminata*, Mart. & Gal. Bull. Acad. Brux. xi. 1, 127. — Southern Mexico, *Galeotti*, nos. 2631, 2632; Oaxaca, Sierra de San Felipe, altitude 3072 m., *Pringle*, no. 4710, vicinity of La Parada, altitude 2300 to 2700 m., *E. W. Nelson*, no. 1015.

++ ++ Flowers axillary or mostly terminating the branches in pairs: fruit distinctly baccate.

22. **G. Aschenbornii**, Schauer. Perennial, many stemmed from the base: stems reclining or ascending, 3 to 5 dm. or more in length, glabrous or minutely hispidulous: leaves in fours, linear-oblong to elliptic-oblong, occasionally somewhat oblong-lanceolate, 0.5 to 1.5 cm. long, 2 to 5 mm. broad, acute, or cuspidate-acuminate, oblong-punctate beneath with a large gland or cluster of glands on the lower surface near the apex, glabrous or hispidulous on the margins: flowers at least in the dried state a greenish yellow; lobes of corolla cuspidate-acuminate: pedicels glabrous, in fruit 2 to 6 mm. in length: mature fruit about 5 mm. in breadth. — Linnæa, xx. 701. *G. geminiflorum*, Mart. & Gal. Bull. Acad. Brux. xi. 1, 126; Walp. Rep. vi. 17; Hemsley, Biol. Cent.-Am. Bot. ii. 64, & v. t. xli. f. 1–3. — Valley of San Luis Potosi, *Schaffner*, no. 841; Zimapan, *Th. Coulter*, no. 189; Jalisco, volcano of Colima, *Marcus E. Jones*, no. 218; Federal District, under pines, base of Sierra de Ajusco, altitude 2460 m., *Pringle*, no. 6597; Orizaba, *Müller*, no. 1444, *Galeotti*, no. 2604, and according to Hemsley, *Liebmann*, no. 236; Guatemala, *Donnell Smith*, no 1970, *Heyde* & *Lux*, no. 3975 (of Donnell Smith's sets), the latter distributed as *Relbunium hypocarpium*, Hemsl., and according to Hemsley, Biol. Cent.-Am. Bot. l. c., *Bernoulli*, no. 292.

* * More or less suffruticose plants, hirsute-pubescent throughout: leaves in whorls of four to seven.

+ Stems 5–7-angled.

23. **G. angulosum**, Gray. Fruticose: stems 5–7-angled, covered below with a grayish bark; branches divaricately spreading, hirsute-pubescent especially on the angles: leaves in whorls of four to seven, linear-oblong or somewhat elliptic-oblong, 6 to 10 mm. long, 2 to 4 mm. broad, acute, slightly cuspidate-acuminate, hirsute-pubescent on the

upper surface and on the prominent midrib beneath, margins ciliate: flowers axillary or terminating the stems and short lateral branchlets: corolla glabrous, greenish white; lobes broadly oblong-ovate, acute: pedicels of the young fruit nearly 2 mm. in length, somewhat thickened, glabrous or sparingly hirsute: immature fruit glabrous, seemingly baccate. — Proc. Am. Acad. xi. 74, 115. — Guadalupe Island, off Lower California, *Palmer*, no. 36.

+ + Stems 4-angled.

24. **G. pubens**, Gray. A stout herbaceous perennial: stems apparently becoming somewhat indurated at the base: leaves in fours or rarely in fives, broadly ovate, ovate-oblong or oblong-linear, 5 to 15 mm. long, 2 to 8 mm. broad, acute or shortly subacuminate, hirsute-pubescent on either surface, the scattered hairs of the upper surface often curved or subuncinate, margins slightly hispid: flowers axillary or cymose: pedicels recurved, pubescent: immature fruit minutely pubescent, distinctly baccate: male plants more profusely flowered. — Proc. Am. Acad. vii. 350, Bot. Cal. i. 285, & Syn. Fl. N. A. i. pt. 2, 40. — California, *Bolander*, no. 6346, *Torrey*, no. 188; Lower California, near Ensenada, 12 April, 1882, *Marcus E. Jones*, also from Lower California, collected by *Orcutt* in 1883, without number.

§ 4. Species of doubtful affinity.

25. **G. ? denticulatum**, Bartl. Stems diffusely branching, hispidulous-setose: leaves in fours, ovate, cuspidate, remotely dentate-ciliate, subhirsute upon either surface, 1-nerved: flowers few, terminating the stems, usually in threes: pedicels capillary: fruit glabrous? — In DC. Prod. iv. 612; Hemsley, Biol. Cent.-Am. Bot. ii. 64. — Mexico, Real del Monte, *Hænke*. Specimens not seen. Description compiled from De Candolle's Prodromus.

RELBUNIUM, Endl. (Name a Latinization of *relbun*, which Feuillée states to be the vernacular for a Chilian dye plant, the *Relbunium hypocarpium* of Hemsl.) — Flowers perfect, subtended by a 2–4-bracteate involucre. Calyx-tube globose; limb obsolete. Corolla rotate, 4-lobed; lobes valvate. Stamens 4, exserted, adnate to the tube of the corolla; filaments short; anthers dithecous. Ovary 2-celled; styles 2, free or connate at the base; stigmas capitate; ovules solitary in the cells, borne on the dissepiment, amphitropous. Fruit didymous, more or less fleshy or baccate, smooth and glabrous, or hirsute, usually two- or by absorption one-seeded. Seeds concave on the face: embryo curved; cotyledons foliaceous; radicle inferior. — Herbaceous perennials having the habit, flowers, and foliage of *Galium*, but with the leaves in whorls of four, axillary inflorescence, involucrate flowers, and usually fleshy fruit. — Gen. Pl. 523 (as a section under *Galium*); Benth. & Hook. f. Gen. ii. 149; Schumann in Fl. Bras. vi. pt. 6, 103; Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 4, 154. *Galium* § *Relbunium*, Gray, Syn. Fl. N. A. i. pt. 2, 40, in part.

§ 1. Involucre of two bracts: fruit pedicellate.

1. **R. sphagnophilum.** A slender delicate annual, pale green, glabrous throughout: stems reclining, rooting at the nodes; internodes 2 to 12 mm. in length: leaves ovate-elliptic, 2 mm. long, one half to two thirds as broad, acute, narrowed below into a subpetiolate base: peduncles axillary, solitary, 2-bracteate above; bracts minute, less than 1 mm. in length: corolla not seen: fruit baccate, glabrous, about 1 mm. in breadth. — Collected by *C. G. Pringle* in sphagnum on the Sierra de Clavellinas, Oaxaca, altitude 2770 m., 17 October, 1894, no. 5812. Probably a near relative of the South American *R. humile*, Schumann.

§ 2. Involucre of four bracts: fruit sessile or nearly so.

* Leaves elliptic to obovate: plant hirsute-pubescent.

2. **R. hypocarpium**, Hemsl. Annual: stems 1 to 10 dm. long, pilose: leaves membranous, 5 to 15 mm. long, 3 to 8 mm. broad, rounded and usually obtusely mucronate at the apex, entire, ciliate, slightly narrowed at the base, pubescent upon either surface, dark green above, paler beneath: peduncles 5 to 15 mm. long: bracts of the foliaceous involucre ovate, acute or obtusish, narrowed into a subpetiolate base: flowers sessile; lobes of the corolla ovate, acutish, ciliate: fruit black or reddish, hirsute. — Biol. Cent.-Am. Bot. ii. 63. *R. hypocarpum*, Schum. Fl. Bras. vi. pt. 6, 112, t. 92. *Rubia hypocarpia*, DC. Prodr. iv. 591; *Valantia hypocarpia*, L. Syst. Nat. ed. 10, 1307. *V. hypocarpa*, L. Spec. ed. 2, ii. 1491. — Jalapa, *C. L. Smith*, no. 1570; Mirador, *Liebmann*, no. 225; Orizaba, *Müller*, nos. 1551, 1699, *Sumichrast*, no. 468; Oaxaca, *Pringle*, no. 5629; Guatemala, *von Türckheim* (no. 721 of Donnell Smith's sets).

* * Leaves ovate-oblong to oblong-lanceolate: plant glabrous.

3. **R. lævigatum**, Hemsl. Stems cespitose, diffusely branched: leaves ovate-oblong or ovate-lanceolate: peduncles axillary: flowers sessile and solitary in the involucre: fruit glabrous. — Biol. Cent.-Am. Bot. ii. 63. *Rubia lævigata*, DC. Prodr. iv. 591 (whence above description). *Galium lævigatum*, Bartl. in DC. Prodr. iv. 591. — Collected in Mexico by *Hænke*. Specimens not seen.

* * * Leaves lanceolate to lance-oblong, pubescent or at least ciliated; margins not conspicuously thickened.

4. **R. hirsutum**, SCHUMANN. Low prostrate many-stemmed herbaceous perennial; stems 4-angled, covered upon the somewhat thickened angles by a spreading hirsute pubescence: leaves lance-oblong, a centimeter or less in length, 2.5 to 3 mm. broad, hirsute-pubescent upon the upper surface and upon the midrib beneath, ciliate: the 1-flowered involucres solitary in the axils; their peduncles about equalling the leaves. — Fl. Bras. vi. pt. 6, 116. *Galium hirsutum*, Ruiz & Pavon, Fl. Peruv. i. 59.

The above description has been drawn from South American material, which well accords with the original characterization of the species by Ruiz and Pavon. No Mexican specimens have been seen by the writer. To this species, however, Martens and Galeotti in Bull. Acad. Brux. xi. pt. 1, 126, doubtfully refer *Galeotti's* no. 2650, collected on rocks near Mirador, Vera Cruz.

5. **R. ciliatum**, HEMSL. Low herbaceous plants: stems obtusely 4-angled, glabrous, leaves narrowly lanceolate, 1 cm. or less in length, acute, glabrous upon either surface, margin ciliate: peduncles axillary, solitary, slender, 3 to 5 mm. long; bracts of the involucre somewhat unequal, narrowly lanceolate, acute, ciliate: flowers sessile: fruit glabrous. — Biol. Cent.-Am. Bot. ii. 62. *Galium ciliatum*, Ruiz & Pav. Fl. Peruv. i. 59. *G. involucratum*, HBK. Nov. Gen. & Spec. iii. 335. *Rubia ciliata*, DC. iv. 591. — South Mexico in woods of El Sabino near the city of Mexico, *Galeotti*, no. 2596, acc. to Martens & Galeotti, Bull. Acad. Brux. xi. pt. 1, 126.

The typical plant is a native of Western South America. No Mexican or Central American specimens belonging to this species have been seen by the writer.

* * * * Leaves lance-linear to linear, more rigid; margins conspicuously thickened.

6. **R. microphyllum**, HEMSL. Glabrous throughout: stems rising from a perennial base, erect or nearly so, 1 to 3 dm. high, much branched above; branches obtusely 4-angled, faces somewhat furrowed: leaves 5 to 15 mm. long, usually pungent-tipped; margins revolute, thickened, smooth: peduncles axillary, solitary: bracts of the involucre similar to the leaves but smaller: flowers sessile; corolla-lobes ovate, obtusish: fruit glabrous or rarely slightly granulose, sessile or short-pedicellate. — Biol. Cent.-Am. Bot. ii. 63. *Galium microphyllum*, Gray, Pl. Wright. i. 80 & Syn. Fl. N. A. i. pt. 2, 41. — New Mexico, *Wright*, nos. 234,

420, 1111, Pinos Altos Mts., *Greene*, no. 145; Arizona, ravines about Camp Grant, 23 April, 1867, *Palmer*, no. 106, banks south of Camp Apache, *Rothrock*, no. 271, Santa Catalina Mts., and at Ft. Bowie, *Lemmon*, no. 127, also on Santa Catalina Mts., altitude 770 to 925 m., 17 April, 1881, *Pringle*, *Lemmon*, no. 527; Texas, El Paso, *Thurber*, nos. 179, 1118, at Belknap, *Sutton Hayes*, no. 327; N. W. Mexico, *Seemann* (without number); Sonora, about Hermosillo, *Crawford*, 1888; S. W. Chihuahua, August to November, 1885, *Palmer*, no. 413; Coahuila, Mts., 14.5 km. east of Saltillo, July, 1880, *Palmer* (without number); region of San Luis Potosi, *Schaffner*, no. 842 a, and at Soledad, 40 km. southwest of Monclova, September, 1880, *Palmer*, no. 415; Morelos, at Tres Marias near Cuernavaca, altitude 2920 m., *Pringle*, no. 7233. A species on the one hand, through var. *setulosum*, approaching the South American *R. ciliatum*, Hemsl., and on the other, through the var. *hispidulum*, the Mexican *R. polyplocum*, Hemsl.

Var. **setulosum.** Leaves setulose-ciliate: fruit granulose-hispid, otherwise like the species. — *R. microphyllum*, Hemsl. Biol. Cent.-Am. Bot. ii. 63, in part. — Zimapan, *Th. Coulter*, no. 186; region of San Luis Potosi, *Parry* & *Palmer*, nos. 309, 310.

Var. **hispidulum.** Habit of the species proper: stem and leaves covered with a scattered short hispidulous pubescence: fruit essentially glabrous, or somewhat granulose. — *R. polyplocum*, Hemsl. Biol. Cent.-Am. Bot. ii. 63, in part. — Valley of San Luis Potosi, *Schaffner*, no. 842; region of San Luis Potosi, altitude 1850 to 2460 m., *Parry* & *Palmer*, no. 308. Approaching the following species in the character of the pubescence, but having a distinctly different habit.

7. **R. polyplocum**, Hemsl. Herbaceous, closely hispidulous-pilose throughout: stems much branched forming dense mats; branches very slender, obtusely tetragonal as in the preceding species: leaves acute or obtusish, not distinctly cuspidate-tipped: flowers solitary, sessile in the small involucral bracts: fruit sessile or nearly so, small, white-granulose or glabrous. — Biol. Cent.-Am. Bot. ii. 63. — Southern Mexico, Mirador, *Liebmann*, no. 244, and (according to Hemsley) no. 243; also *Linden*, no. 516.

R. Aschenbornii, Hemsl. Biol. Cent.-Am. Bot. ii. 62, is *Galium Aschenbornii*, Schauer, treated above.

II. DIAGNOSES OF NEW AND CRITICAL MEXICAN PHANEROGAMS.

Tradescantia brachyphylla. Stems erect, 2 to 3 dm. high, branching from the base, glabrous except along a line ascending from the axil of each leaf: internodes 2 to 5 cm. long: leaves sessile, ovate-oblong, 1.5 to 2 cm. long, two thirds as broad, acute, glabrous on either surface, ciliate: flowers in sessile umbels terminating the stems and branches; pedicels about 1.5 cm. long, glabrous or with a scattered pubescence: sepals oblong, navicular, 6 mm. long, obtusish, glabrous or with a few hairs on the thickened keel: petals roseate, broadly ovate, obtuse, 6 to 7 mm. long, two thirds as broad: the alternating stamens longer and shorter respectively; filaments all bearded: ovary and style glabrous; stigma subcapitate: mature capsule 3 mm. long: seeds oblong, 1.5 mm. long, rugose; embryotega dorsal. — Collected by C. G. Pringle on dry limestone ledges near Tehuacan, altitude 1538 m., 29 July, 1897, no. 6679.

TRADESCANTIA HOLOSERICEA, Kunth, Enum. Pl. iv. 92. Specimens collected by Rev. Lucius C. Smith in the Clavellinas, State of Oaxaca, altitude 2770 m., 26 June, 1894, no. 66, and also by C. Conzatti and V. González on the Cerro de San Felipe, altitude 3000 m., 25 July, 1897, no. 229, but for the larger leaves agree in all essential details with Kunth's excellent description of the above species. The leaves in the specimens at hand are sessile, ovate-oblong, acuminate, 6 to 20 cm. long, 2.5 to 8.5 cm. broad. The flowers are violet or purple, and the bracts also are often more or less colored.

Tradescantia longifolia. *Dichorisandra longifolia*, Mart. & Gal. Bull. Acad. Brux. ix. 378 (reprint p. 7). Excellent specimens of this species from Southern Mexico, and agreeing well with the original description of Martens and Galeotti, prove to be quite distinct from *T. holosericea,* Kunth, under which species the plant under consideration has been placed as a variety. The following description may be appended: — roots fascicled, tuberous: stems erect or nearly so, 2 to 5 dm. high, simple or sparingly branched from near the base: leaves lance-attenuate, 10 to 15 cm. long, 1.5 to 3 cm. broad, villous-pubescent upon either surface, strongly ciliate, especially about the margin of the sheath: inflorescence an open oblong racemose panicle: flowers (in the dried state) 12 to 13 mm. in breadth: sepals oblong, 5 to 6 mm. long, rounded at the apex: the roseate petals obovate, slightly exceeding the calyx: stamens equal or nearly so; filaments strongly bearded: ovary glandular-pubescent above: mature capsule 6 mm. long: seeds rugose. — Collected by Rev. Lucius C. Smith at Cuatro Venados, altitude 2150 m., 27 June, 1894, no. 64; by C. G. Pringle on hills above Oaxaca, altitude 1840 m., 6 August, 1894, no. 5608, and in the same locality, 15 July, 1897, no. 6711.

The species is readily distinguished from *T. holosericea*, Kunth, by the narrower long-attenuate leaves and by the roseate flowers.

Tradescantia macrophylla. Stems 4 to 6 dm. high, pubescent: leaves lance-attenuate, 15 to 25 cm. long, 3 to 4 cm. broad, pubescent upon either surface, ciliate; sheaths about 2 cm. long, somewhat inflated, veiny, more or less pubescent: inflorescence a terminal sparingly branched, villous-pubescent panicle, 8 to 22 cm. long; the lower divisions of the panicle 7 to 10 cm. long: flowers sessile or nearly so, in clusters of 3 to 5 flowers each: calyx glandular-pubescent: sepals navicular, oblong, nearly 5 mm. long, rounded at the apex, 3-nerved, margins scarious: petals equalling or slightly exceeding the calyx, white, streaked with brownish veins, or in the bud pale blue, marcescent: ovary glandular-pubescent above: capsule 5 mm. long: seeds rugose, 3 mm. long. — Collected by C. G. Pringle on bluffs of a barranca near Cuernavaca, 26 July, 1896, no. 7224, and in the same locality, altitude 1538 m., 21 August, 1897, no. 6695.

A well marked species, readily recognized by the long leaves, the close inflorescence, and the white or whitish flowers.

Anthericum platyphyllum. ? *Trachyandra echeandioides*, Schlecht. Bot. Zeit. iii. 629, not *A. echeandioides*, Bak. Roots fascicled, fleshy-fibrous, 1 to 2 dm. long: caudex erect, 1 dm. or more high, surrounded by a rather dense envelope of brownish fibres, the remnants of earlier leaves: leaves basal, narrowly lance-attenuate, 1.5 to 4 dm. long, 12 to 24 mm. broad, pale or livid green, glabrous on either surface with an inconspicuous semi-transparent hirtellous margin: peduncle about 4 dm. high, glabrous, terete, unibracteate, branching above into a racemose paniculate glabrous inflorescence, lateral branches of the panicle 3 dm. long: flowers 2 to 4 in the axils of short scarious bracts: pedicels 3 to 12 mm. long, much exceeding the bracts, glabrous, jointed just below the middle: perianth yellow, 2 cm. broad; divisions oblong, obtuse, 10 to 12 mm. long, 3-nerved, the inner slightly larger: stamens equal; filaments muricate; anthers oblong-linear, about 3 mm. long: capsule oblong, triangular, 1 cm. long, strongly reticulate-nerved: seeds angulate, black. — Collected by C. G. Pringle on dry limestone ledges near Tehuacan, altitude 1540 m., 29 July, 1897, no. 6680.

Zephyranthes Conzattii. Bulbs globose, 2 to 2.5 cm. in diameter, covered with dark brown scales; neck about 2 cm. long: leaves produced after the flowers: peduncle about 15 to 18 dm. long: spathes 2.5 to 3 cm. long, tubular below; valves lance-attenuate: pedicel slender, 3 to 4.5 cm. in length: perianth, in the dried state, rose-colored or crimson-purple in the bud, 5 to 7 cm. in length; tube short, 6 to 8 mm. long, with a lacerated ring in the throat; divisions oblanceolate, 1 to 1.5 cm. broad: stamens of two lengths, the alternating ones longer and shorter respectively, declinate; anthers strongly lunate: the declinate style exceeding the stamens; stigmas deeply 3-cleft; lobes revolute: fruit not seen. — Collected by Professor C. Conzatti, Valley of Oaxaca, altitude 1550 m., 19 April, 1896, no. 98.

A species in some respects corresponding to the description of the little known *Z. lilacina*, Liebm., but with pedicels much shorter than are attributed to that species.

Zephyranthes Nelsonii. Bulbs ovate, 1 to 2 cm. in diameter, covered with dark brown scales; neck 1.5 to 2.5 cm. long: leaves developed with the flowers, 5 to 15 cm. in length, 2 mm. or less wide, glabrous, obtuse: scape 5 to 12 cm. high: 1-flowered spathe 15 to 18 mm. long, scarious, often tinged with a pale rose color, tubular for about two thirds its length, bifid above, the divisions lance-attenuate: pedicel 12 to 20 mm. in length: perianth narrowly funnelform, white with a very slight tinge of rose, about 2.5 cm. high; tube slender, 6 to 7 mm. in length; divisions oblanceolate, 6 to 7 mm. broad, strongly nerved: stamens nearly equal, about two thirds as long as the perianth; anthers 4 to 5 mm. long: style overtopping the stamens; stigmas shortly 3-lobed: capsule about 5 mm. high, nearly twice as broad, glabrous. — Collected by E. W. Nelson, near Santa Domingo, Oaxaca, altitude 500 m., 18 June, 1895, no. 2711 a; also between San Ricardo and Ocozucuantla, Chiapas, altitude 800 to 1000 m., 18 August, 1895, no. 2983.

A species with much the habit of *Z. texana*, Herb., but with a much longer more pronounced perianth-tube, and less divided stigmas. Our plant may eventually prove to be the same as the *Z. Lindleyana*, Herb., but the flowers are somewhat smaller than are ascribed to that species in the original description, and certainly our plant does not well accord with the description of *Z. Lindleyana*, Herb., as drawn by Baker in his Handb. Amaryll. 32.

Cooperia Drummondi, Herb. acc. to Lindl., Bot. Reg. t. 1835. Specimens agreeing in all essential details with the above species were collected by the late Rev. Lucius C. Smith, at Peña de Ejutla, Nacaltepec, in the State of Oaxaca, altitude 2000 m., 1 June, 1895, no. 545; also by C. Conzatti near the city of Oaxaca, altitude 1550 m., 17 May, 1896, no. 146.

This species has been hitherto attributed to Northern Mexico and Texas.

FURCRÆA BEDINGHAUSII, Koch. Wochenschr. 1863, 233; Morr. Belg. Hort. xiii. 327, with fig.; Baker, Handb. Amaryll. 203, & Bot. Mag. t. 7170. To this species may be referred Pringle's no. 6669, collected on lava beds, Serrania de Ajusco, altitude 2600 m., 17 August, 1897, distributed as "Yucca Pringlei," a name given to the plant from fruiting specimens only. Early in the present season Mr. Pringle was successful in securing flowering specimens, which proved beyond a doubt that the affinity of the plant is with the genus *Furcræa,* and not with *Yucca.*

Through the kindness of Mr. J. G. Baker, of the Royal Gardens, Kew, Mr. Pringle's plant (notwithstanding its somewhat smaller leaves) has been identified with the above species.

Corallorhiza involuta. Aphyllous, glabrous throughout, the entire plant purplish: roots coralloid: stems 1 to 2.5 dm. high, provided with three sheathing obtuse bracts: racemes few–several-flowered: floral bracts short: perianth purple, about 12 mm. in diameter; sepals oblong, somewhat narrowed toward the apex, 6 mm. long, about one third as broad, 3-nerved, the lateral sepals a little unequal at their bases forming a slight gibbosity: petals oblong, obtuse, 3-nerved, nearly equalling the sepals: labellum deep purple with a yellowish base, oblong, thickened, 6 mm. long, about one half as broad with an obtuse blunt almost truncate apex, provided near the base with a thick cushion-like body, margins strongly involute: clinandrium somewhat arched, about 3 mm. long. — Collected by C. G. Pringle under oaks on the summit of Sierra de San Felipe, Oxaca, altitude 2925 m., 16 June, 1894, no. 5874.

This may possibly prove to be the same as the *C. bulbosa*, Rich. & Gal., but the base of the plant is not bulbous, and there is no correspondence with the character "hinc et illinc lobulo obtuso aucto."

CORALLORHIZA MEXICANA, Lindl. Gen. & Sp. Orch. 534. Specimens collected by Mr. C. G. Pringle on the Sierra de San Felipe, Oaxaca, altitude 2750–3000 m., June, 1894, no. 4690, also in the same locality by C. Conzatti and V. González, 12 September, 1897, no. 461, are referred doubtfully to the above species. In view of the very meagre descriptions of the Mexican species of this genus, it seems advisable to append the following description of the specimens in question.

Plant glabrous throughout, aphyllous: stems from an ascending rhizome, 3 to 7 dm. high, purplish, provided with 2 to 4 sheathing obtuse or acutish somewhat scarious nerved bracts: racemes many-flowered; rhachis subangulate; floral bracts small, scarious: perianth 1.5 cm. broad, yellowish white or purplish in the dried state, pedicellate, at first erect, later reflexed; the persistent sepals about 7 mm. long, nearly 3 mm. broad, obtuse, 3-nerved, the upper oblong the lateral oblong-lanceolate, slightly oblique, prolonged at the base into a short gibbous adnate spur; petals oblong, obtuse, often somewhat oblique, 3-nerved, a little shorter than the sepals; labellum 6 to 7 mm. long, yellowish white, dotted with purple, short-unguiculate, 3-lobed, 3-nerved from the base, lateral lobes short, somewhat falcate, obtuse, rounded or sometimes emarginate, the median lobe obovate-cuneate, subtruncate or retuse, entire, occasionally irregularly crenate, bilamellate at the base on either side of the midnerve, between the lateral sinuses, rather densely papillate on the upper surface, 5-nerved from the branching of the two lateral nerves just above the sinus on either side: clinandrium somewhat arched, about 5 mm. long: capsule oblong-obovoid, 12 to 17 mm. long, reflexed. A species as stated by Lindley "very like *C. multiflora*," but differing in the lobing of the lip, the papillate character, and the venation of the same, as well as the shorter lamellæ.

Corallorhiza Pringlei. Glabrous throughout, aphyllous: stems slender, 1 to 3.5 dm. high, more or less scaly-bulbous at the base; caudex provided with 1 to 3 sheathing bracts: racemes rather few-flowered; floral bracts minute, shorter than the pedicels, the latter 2 to 3 mm. in length: flowers small, 5 to 8 mm. in breadth when fully expanded; sepals oblong-lanceolate, obtuse, inconspicuously 3-nerved, 3 to 4 mm. long, about 1 mm. broad, exceeding in length the obtuse slightly broader lateral petals, both sepals and lateral petals marked with a semi-translucent oblong punctation; lip white variegated with purple, ovate-rotund or sometimes slightly obovate-rotund, narrowed at the base into a short claw, strongly emarginate at the apex, with an irregular crenate margin, 3–5-nerved, bearing two somewhat diverging lamellæ about one third distant from the base; clinandrum short, thick, about 2 mm. long: capsule oblong-elliptic, 7 mm. long, reflexed on slender pedicels. — Collected by C. G. Pringle on shaded banks, Las Sedas, Oaxaca, altitude 2000 m., 1 November, 1894, no. 5804; and on the Sierra de San Felipe, altitude 2600 m., 13 December, 1895, no. 6295.

Distributed in 1895 as *C. Mexicana*, Lindl., from which it is distinguished by the more slender habit, smaller flowers, and by the well marked characters of the lip.

EPIDENDRUM ELEGANS, Rchb. f. in Walp. Ann. vi. 374. *Barkeria elegans*, Knowles & Wescott, Fl. Cab. ii. 7, t. 49. This rare and beautiful orchid has been rediscovered by Mr. Pringle on limestone ledges near Tehuacan, altitude 1540 m., 31 July, 1897, no. 6769.

The species is readily recognized by its upright leafy stem, terminal racemose inflorescence, long bracteate-sheathed peduncle, and finally by the beautiful lilac-purple flowers (3–5 cm. broad), and the oblong usually undivided lip, which is adnate to the base of the column for one fourth the length of the latter organ.

CELTIS MONOICA, Hemsl. Biol. Cent.-Am. Bot. iii. 139, v. t. 77. Excellent fruiting specimens of this species were collected by Mr. E. W. Nelson on Maria Madre Island of the Tres Marias group of islands, 3–25 May, 1897, no. 4236. The leaves in Mr. Nelson's specimens are more distinctly serrate than in the type, but they have exactly the same outline, venation, and pubescence. The following description of the fruiting characters may be appended: — pedicels axillary, solitary, ascending or erect, 1 cm. or less in length, appressed-puberulent: mature fruit oblong-ovate, 10 to 12 mm. long, 6 to 8 mm. thick, subtriangular, glabrous: the undivided styles persistent.

The above species is readily recognized on account of the distinctly pinnate venation of the leaves, while in most of the species of the genus the leaves are 3-nerved from the base.

Pouzolzia Pringlei. Shrub: stems and branches covered with a grayish brown bark, dotted with scattered lenticels; the branchlets pubescent: leaves oblong-ovate or elliptic-ovate, 1.5 to 4 cm. long, 10 to 18 mm. broad, obtuse or acute, entire, ciliate, 3-nerved from the cuneate or rounded base, pubescent above, densely white-tomentose beneath; petioles pubescent, 3 to 10 mm. long; stipules triangular-acuminate, about 3 mm. long, ciliate, 1-nerved, pubescent on the outer or lower surface: flowers monœcious, disposed in dense axillary clusters: staminate flowers, 3–4-merous: the short bidentate perianth of the fertile flowers much exceeded by the long prominent style; fruiting perianth ovate, short-acuminate, about 2 mm. long, pubescent, somewhat tuberculate-winged, completely enclosing the ovate acute smooth white shining akene. — Collected by C. G. Pringle in Tomellin Cañon, altitude 1230 m., 9 July, 1897, no. 6736.

A species somewhat resembling *P. nivea*, Watson, but with oblong leaves and shorter stipules.

Ruprechtia Pringlei. Shrub or small tree 4 to 6 m. high: stems and branches terete, smooth, covered with a grayish bark: leaves oblong-ovate or slightly obovate, 4 to 7 cm. long, 2 to 3.5 cm. broad, abruptly acuminate to an obtusish apex, entire or somewhat repand, narrowed at the base to a short petiole, glabrous above except on the puberulent midrib, pubescent below, the midrib and veins prominent on the lower surface, nerves not strongly reticulated: petioles barely 3 mm. in length: ochræ about 2 mm. long, deciduous: fruiting calyx 2.5 cm. long; tube 4 mm. long; inner divisions of the calyx small, linear, acute: akene narrowly ovate-acuminate, glabrous below, above bearing a trace of pubescence on the acute angles, the lower portion triangularly 3-lobed with shallowly furrowed lobes and rather deeply sulcate faces. — Collected by C. G. Pringle in Tomellin Cañon, Oaxaca, altitude 925 m., 7 December, 1895, no. 7008.

A species in general aspect similar to *R. fusca*, Fern., but with differently outlined and less reticulately veined leaves, smaller fruiting calyx, and essentially glabrous akene.

Iresine discolor. Shrub: stems terete, covered with a grayish bark and often dotted with numerous lenticels, the ultimate branches finely tomentose, somewhat compressed at the nodes: leaves opposite, petiolate, ovate-lanceolate, elliptic-lanceolate, or sometimes ovate, acute, 1 to 5 cm. long, 5 to 20 mm. broad, usually strongly discolorous, finely pubescent or even tomentose and granulose above, densely soft-tomentose beneath, acute or obtusish at the apex, margin entire, narrowed at the base into a short pubescent petiole; petioles 3 to 6 mm. long: inflorescence of rather small panicles terminating the branches; the branches of the panicles bearing pedicelled spikelets with tomentose rhachises; bracts scarious, broadly 1-nerved, ovate, obtusish: flowers diœcious: staminate flowers about 2 mm. long; divisions of the calyx scarious, oblong-elliptic, obtuse; stamens united at the base into a short cup, the 5 staminodea two thirds as long as the filaments, hirtellous; the rudimentary ovary with sessile shortly 2-lobed stigmas: pistillate flowers about 2 mm. long; calyx divisions elliptic-lanceolate, acutish, distinctly 1-nerved, with scarious margins; ovary glabrous; styles short with 2 (to 3) long slender stigmas. — Collected by C. G. Pringle and C. Conzatti in Santa Catarina Cañon, altitude 1000 m., 4 July, 1897, Conzatti's no. 231; also by C. G. Pringle in Tomellin Cañon, altitude 1230 m., 4 July, 1897, no. 6713, and in the same locality, altitude 1000 m., 17 May, 1894, no. 5787. The latter number, although differing slightly in foliar characters, has the same floral structure, and is said by Mr. Pringle to be the same as no. 6713.

Batis maritima, L. Syst. Nat. ed. 10, 1176. This species, not hitherto definitely known to occur in Mexico, has been collected by Mr. Nelson on Maria Magdalena Island of the Tres Marias group of islands, 26–28 May, 1897, no. 4327.

THELYPODIUM LONGIFOLIUM, Watson, Proc. Am. Acad. xvii. 321. To this species may be referred Pringle's no. 6548, from the Valley of Mexico, 30 September, 1896, distributed under *T. micranthum*, Watson, and later described by Professor Edward L. Greene, Pittonia, iii. 247, as *T. anisopetalum.*

ERYSIMUM MACRADENIUM, Gay, Erys. Nov. 8. Excellent specimens of this interesting species, both in flower and fruit, were collected by C. Conzatti and V. González on the summit of the Sierra de San Felipe, Oaxaca, 15 August and 26 September, 1897, no. 499. The species is well marked by the large placental glands, and by the long capsules (15 to 16 cm. in length).

Phyllanthus subcuneatus. Suffruticose, about 1 m. high, glabrous throughout: stems and branches covered with a grayish bark, the younger shoots reddish: leaves alternate, often subfascicled, petiolate, obovate, obovate-cuneate or distinctly cuneate, 3 to 10 mm. long, two thirds as broad, rounded, subtruncate or retuse at the apex, entire, somewhat paler beneath; petioles 1 to 1.5 mm. long; stipules minute, about 1 mm. in length: flowers axillary: staminate flowers about 3 mm. broad, short-pedicellate; pedicels 1 to 4 mm. long: calyx 6-parted; divisions oblong or oblong-ovate, rounded at the apex, 1-nerved, margins scarious: stamens monadelphous; anthers 3 at the top of the column; glands 6, distinct: pistillate flowers 3 to 4 mm. broad, on slender pedicels, 6 to 9 mm. long: calyx 6-parted; the divisions obovate, rounded or obtusish at the apex, green; the disk cupulate, 6-lobed: ovary glabrous; styles united at the base only, spreading; stigmas slightly 2-lobed: capsule about 3 mm. in diameter, slightly broader than long: seeds triangular, about 2 mm. long, with a reddish brown minutely roughened surface. — Collected by C. G. Pringle on limestone ledges near Tehuacan, altitude 1540 m., 29 July, 1897, no. 6753.

Argithamnia neo-mexicana, Müll. Arg., var. **depressa.** Stems numerous, prostrate from a woody perennial base: leaves oblanceolate, 2.5 to 4 cm. long, about 8 mm. broad, narrowed below into a subpetiolate base, glabrate: calyx-divisions of the fertile flowers a little shorter and somewhat less acuminate than in the type: seeds conforming to the species proper. — Collected by C. G. Pringle on calcareous plains of Tehuacan, altitude 1540 m., 29 July, 1897, no. 6752.

EUPHORBIA LACERA, Boiss. Euph. Cent. 22, & Euph. Ic. t. 30. A number of specimens of this species at hand show the foliage to be extremely variable. The leaves are ovate, elliptic-oblong to linear, 2 to 12 cm. long, 2 to 18 mm. broad, deeply incised-dentate (especially toward the base) to entire, usually with one or two larger divaricate triangular teeth at the base of the blade, which give the leaves a halberd-shaped appearance. The bicornute greenish appendages of the four glands of the involucre and the tetragonal seeds associated with the dichotomously branching glabrous stems, notwithstanding the strongly polymorphous character of the leaves, readily distinguish this species from *E. heterophylla*, L., with which it has been confused. The following specimens may be referred to *E. lacera:* Valley of San Luis Potosi, Schaffner, no. 859 (in the Gray Herbarium under *E. heterophylla*, L., var.); Sierra de San Felipe, Oaxaca, altitude 2300 m., 11 September, 1894, Pringle, no. 5619; at El Parin, Oaxaca, altitude 1230 m., 3 October, 1894, Pringle, no. 5707; also Pringle's no. 6685, collected on limestone hills near Tehuacan, altitude 2000 m., 30 August, 1897.

EUPHORBIA PROSTRATA, Ait. Hort. Kew. ed. 1, ii. 139. To this species may be referred Pringle's no. 6436, *Euphorbia ramosa*, Seaton, var. *villosior*, Greenman, Proc. Am. Acad. xxxii. 297, also Pringle's no. 6683, collected on dry limestone ledges, Tehuacan, altitude 1540 m., 27 August, 1897; both specimens correspond well with Parry and Palmer's no. 818, Karwinski's specimen from Mexico without further data, and also with other authentic material.

The *E. ramosa*, Seaton (Proc. Am. Acad. xxviii. 121), is very closely allied to, if not specifically the same as *E. prostrata*, Ait., differing only in the glabrous capsules, and the less villous character of stem and leaves. The mature seeds in all the specimens mentioned above are grayish, subquadrangular, somewhat furrowed, more or less transversely rugose, and distinctly foveolate or honeycombed. The less mature seeds are more apt to be reddish, and more distinctly furrowed.

Euphorbia (Alectoroctonum) tricolor. Suffruticose, 1 m. or less in height: stems and branches covered with a grayish red bark, somewhat striated, puberulent on the young shoots; nodes 1 to 6 cm. distant: leaves petiolate, ternate, quaternate, or the uppermost opposite, oblong-ovate, 1 to 2 cm. long, two thirds as broad, glabrous above, sparingly pubescent beneath, rounded at the apex, entire, cuneate at the base; petioles pubescent, 4 to 8 mm. long; stipules glandular: inflorescence in terminal usually close cymes: involucre wine-colored or sometimes greenish, strigillose-pubescent on the outer surface, also pubescent within; lobes laciniate; glands subbilabiate, bearing oblong-ovate entire or slightly toothed showy appendages, these on the outer surfaces at the base a deep wine color, above which is an area of purple or deep rose color, and this again tipped with white: ovary rather long-stiped, glabrous; styles bifid, about three fourths free, somewhat thickened: capsule obtusely triangular, 6 mm. long, 5 to 6 mm. in diameter: seeds ecarunculate, tetragonal, slightly roughened, 4 mm. long. — Collected by C. G. Pringle on dry calcareous bluffs near Tehuacan, 29 August, 1897, no. 6682.

Euphorbia (Cyttarospermum) violacea. Perennial, dichotomously branched from the base, 1 to 3 dm. high: stems and branches more or less angled and striate, glabrous or with a few scattered hairs, hispidulous at the nodes: nodes from 1 to 7 cm. distant: upper leaves opposite, the lower alternate, narrowly oblong or oblong-lanceolate, 1 to 4.5 cm. long, 2 to 8 mm. broad, glabrous or nearly so above, scattered hirtellous-pubescent beneath, acutish, entire, hispidulous on the margins, narrowed or attenuate at the base into a rather broad thickish petiole; petioles 2 to 10 mm. long; stipules glandular: inflorescence in terminal pedunculate cymes: bracts minute, pubescent: involucres turbinate, somewhat pubescent on the outside, greenish violet to almost black, with 5 oblong laciniate-truncate lobes, and 5 glands; glands oblong with oblong-rotund violet-colored white-margined appendages, 1 mm. or more in length: ovary long-stipitate, glabrous; styles 2-parted to the base: capsule obtusely triangular, 3 mm. in length, slightly broader than long; seeds ecarunculate, ovate, foveate, 2 mm. long. — Collected by C. G. Pringle on limestone hills near Tehuacan, altitude 2000 m., 30 August, 1897, no 6681.

A well marked species, readily recognized by the beautifully violet-colored involucre and glandular appendages.

Euphorbia xylopoda. Much branched from a woody perennial base, 2 to 9 dm. high, glabrous throughout: stems terete, subglaucous: cauline leaves alternate, the uppermost subverticellate, elliptic or oblanceolate, 1.5 to 4 cm. long, 5 to 12 mm. broad, acute or acutish, mucronate, entire, narrowed below to a short petiole, light green above, paler and almost glaucous beneath; petioles 2 to 5 mm. in length; stipules reduced to minute glands: involucres terminal, solitary, sessile, glabrous, 5-lobed, subtended by about three ovate or obovate short-acuminate much reduced more or less colored floral leaves, ciliated at the base; lobes broad, dentate-fimbriate; glands 5, oblong, sessile or nearly so, exappendiculate: ovary 3 mm. long, glabrous; style 3-parted; stigmas 2-lobed, fleshy: mature capsule depressed, obtusely triangular, about 7 mm. long, 8 mm. in diameter, glabrous: seeds oblong, 4 mm. long, smooth, carunculate. — Collected by C. G. Pringle on the hills of Las Sedas, Oaxaca, altitude 1850 m., 22 July, 1897, no. 6698.

A species belonging apparently to the section *Poinsettia* and having its affinity with *E. restiacea*, Benth., from which it is distinguished by the larger broader leaves, the broad lobes of the involucre, and by the presence of five glands.

Buxus pubescens. Shrub or small tree 4.5 to 8 m. high: stems and branches covered with a grayish bark; the branchlets and younger shoots provided with a soft spreading pubescence: leaves opposite or occasionally subalternate, sessile or nearly so, rhombic-ovate to oblong-ovate, 2 to 5 cm. long, 1.5 to nearly 3 cm. broad, 3-nerved, obtuse or acutish, mucronate, cuneate at the base, entire, ciliate, soft-pubescent beneath, more sparingly pubescent and glabrate above showing the reticulate venation on the upper surface: inflorescence of axillary short-pedunculate much contracted subracemose pubescent floral clusters: staminate flowers pedicellate; pedicels 3 mm. long, about twice exceeding the ovate acute bracts: calyx deeply 4-parted; divisions ovate, acute, 2 mm. long, the inner divisions slightly broader than the outer ones: the rudimentary pistil somewhat quaterfoil or X-shaped: fertile flowers about 5 mm. long, single, sessile, terminating the inflorescence; ovary glabrous: fruit not seen. — Collected on Maria Madre Island by E. W. Nelson, 3–25 May, 1897, no. 4221.

A species apparently endemic in the Tres Marias Islands, and most nearly related to the West Indian *B. pulchella*, Baill.

Metastelma macropoda. Stems twining, slender, terete, above as well as the branches decussately pubescent in two lines: leaves petiolate, elliptic-oblong to elliptic-lanceolate, 1.5 to 2.5 cm, long, 4 to 7 mm. broad, mucronate or simply acute at the apex, narrowed below to a rounded or obtusish base, glabrous on either surface, or slightly puberulent on the midrib above, margins ciliolate, usually revolute; petioles 2 to 4 mm. long, puberulent above, glabrous beneath: peduncles 3 to 18 mm. long, these as well as the pedicels minutely pubescent; pedicels 2 to 3 mm. long: flowers small: calyx-lobes ovate, obtuse, about 1 mm. long, margins scarious: corolla white or cream-colored, about 4 mm. in breadth; lobes elliptic-oblong, obtusish, rather closely pubescent above: column short: mature fruit not seen. — Collected by C. G. Pringle in Tomellin Cañon, altitude 1540 m., 17 July, 1897, no. 7606.

Most nearly related to *M. pedunculare*, Decne., but differing in the foliar characters, smaller flowers, shorter claw, pubescence on the corolla-lobes, and also by having a shorter column.

Gonolobus caudatus, Gray, var. **trachyanthus.** Shrubby, 3 to 6 dm. high: leaves petiolate, lanceolate, attenuate, glabrous, 2.5 to 3.5 cm. long, 10 to 15 mm. broad: corolla distinctly puberulent above. — Collected by C. G. Pringle in Tomellin Cañon, altitude 600 m., 24 July, 1897, no. 6654.

Ipomœa dimorphophylla. Stems twining, purplish, more or less pubescent: leaves petiolate, ovate, 4 to 10 cm. long, 3 to 8 cm. broad, acuminate, subcordate, entire or deeply 3-lobed, lobes obtuse, mucronate, pubescent upon either surface especially on the prominent midrib, nerves, and veins beneath; petioles 2 to 5 cm. long, pubescent, often provided with two glandular organs at the base of the leaf-blade: inflorescence in axillary pedunculate 1–several-flowered cymes; peduncles green or greenish purple, 2 to 15 cm. in length, more or less pubescent; pedicels somewhat thickened, about 1 cm. long; bracts and bracteoles caducous: calyx-divisions oblong, 6 to 7 mm. long, nearly equal, the outer slightly shorter, rounded or retuse at the apex, dark brown or almost black with lighter scarious margins: corolla white, open-funnelform, about 6 cm. long: stamens included, one half as long as the corolla; filaments unequal, pilose at the base: style about equalling the stamens: mature capsule and seeds not seen. — Collected by C. G. Pringle in a barranca near Cuernavaca, 4 August, 1896, no. 7241, and in the same locality, altitude 1900 m., 23 August, 1897, no. 6658.

Ipomœa tentaculifera. Glabrous throughout: stems herbaceous, twining, somewhat angled: leaves cordate, entire, acuminate, mucronate, with an open sinus at the base and rounded basal lobes, 8 to 10 cm. long, 5 to 6 cm. broad: petioles 5 to 6 cm. long: peduncles 7 to 12 cm. long, 1-flowered: pedicels about 7 cm. long, much thickened: sepals nearly equal, oblong, 10 to 12 mm. long with a rounded apex and sub-scarious margins, the inner ones slightly longer, the outer covered with herbaceous tentacle-like outgrowths: corolla "violet throughout," open-funnelform, about 7 cm. long: stamens unequal, included, about one third the length of the corolla; filaments villous-pubescent at the base. — Collected by C. G. Pringle in Tomellin Cañon, altitude 1540 m., 17 July, 1897, no. 6702.

A beautiful and well marked species readily recognized by the one-flowered peduncles, the long almost fleshy pedicels, and by the peculiar tentacle-like growths on the calyx.

Cordia insularis. Shrub 3 to 5.5 m. high: stems and branches glabrous, reddish brown, conspicuously dotted with numerous whitish lenticels; the extreme branchlets covered with a hirsute pubescence: leaves scattered, elliptic-ovate or sometimes slightly obovate, 1.5 to 3 cm. long, 1 to 1.5 cm. broad, narrowed below into a short petiole, obtuse, the upper portion more or less deeply crenate-dentate, occasionally sharply toothed, entire toward the base, hispid above, spreading hirsute-pubescent beneath, especially on the midrib and veins: inflorescence capitulate; heads small (after the corolla has fallen, about 5 mm. in diameter): peduncles, during anthesis, 1 cm. or less in length, covered with a spreading hirsute pubescence: calyx 2 mm. long, 5-dentate; teeth short, acute: corolla 3 mm. long, nearly cylindrical with short recurved lobes, externally glabrous, pubescent inside along the line of the filaments: stamens included: style a little exserted. — Collected by E. W. Nelson on Maria Madre Island of the Tres Marias group of islands, 3–25 May, 1897, no. 4296.

Most nearly related to *C. cana*, Mart. & Gal., from which it is distinguished by the more spreading pubescence throughout, the more coarsely dentate and shorter-petioled leaves, and further by the somewhat shorter peduncles.

Specimens collected by Mr. Pringle on lava beds near Zapotlan, State of Jalisco, 27 May, 1893, no. 4389, distributed as *C. cana*, Mart. & Gal., may be the same, although the pubescence on the young shoots, the peduncle, and the calyx is sub-appressed. The leaves in Mr. Pringle's plant are very much reduced, yet they have the spreading pubescence of *C. insularis* rather than of *C. incana*, so that it is difficult to say from the single specimen at hand to what species it may be correctly referred. Further material of Mr. Pringle's plant is necessary for positive determination.

CORDIA SONORÆ, Rose, Contrib. U. S. Nat. Herb. i. 106. Specimens collected by E. W. Nelson on Maria Madre Island, 3–25 May, 1897, no. 4207, agree in all essential characters with the type of the above species. In Mr. Nelson's specimens, however, the leaves are nearly glabrous above, the stamens are included and the style is slightly exserted. As in the type specimen, collected by Palmer at Alaos in 1890, no. 376, the stamens are exserted and the style included, it is evident that the flowers of this species are dimorphic.

Heliotropium axillare. Low, cespitose, covered throughout with a stiff grayish white more or less closely appressed pubescence: stems spreading from a rather deep ligneous root: branches irregularly flattened or somewhat angled: leaves lanceolate or narrowly oblanceolate, 1 to 1.5

cm. long, 2 to 5 mm. broad, narrowed below into a short petiole, obtusish or acute at the apex, closely appressed-pubescent on either surface, margins revolute: flowers axillary, solitary, scattered along the branches from near the base: calyx-divisions lance-linear, acute, about 3 mm. long, slightly unequal: corolla when fully expanded, 8 to 10 mm. broad; tube about equalling the divisions of the calyx; lobes rounded: nutlets about 1 mm. long, slightly hirtellous on the outer upper surface. — Collected by C. G. Pringle on plains near Tehuacan, altitude 1540 m., 29 July, 1897, no. 6749.

Most nearly related to *H. Pringlei*, Rob., from which it is distinguished by the more closely appressed pubescence, the less unequal lobes of the calyx, and also by the more rounded lobes of the corolla.

Heliotropium mexicanum. Suffruticose: stems ascending or erect, 3 dm. or more high, usually much branched, covered below with a brownish pubescent bark, which gradually peels away from the stem, the stems above and also the branches covered with a rather dense reflexed pubescence, and with scattered ascending stiffer hairs intermixed: leaves alternate, short-petiolate, oblong-oblanceolate to narrowly lanceolate, including the petiole 1 to 5 cm. long, 2 to 8 mm. broad, the upper surface hirsute-hispid or sub-strigose with shorter finer hairs intermixed, somewhat channelled by the sunken midrib and lateral nerves, rather densely and finely pubescent beneath with scattered hirsute hairs intermixed especially upon the raised midrib and arched lateral nerves, obtuse or acute, margin entire, revolute: petioles about 1 mm. long: inflorescence in lateral and terminal usually pedunculate false racemes, either simple or in pairs, 2 to 20 cm. in length: flowers sessile or short pedicellate, bracteate: bracts small, subulate, about 2 mm. long: calyx 3 to 4 mm. long, deeply 5-parted; divisions somewhat unequal, linear-oblong, obtuse or occasionally acutish, hirsute-pubescent: corolla white, 5 to 6 mm. long, equally broad when fully expanded, shallowly 5-lobed or pentagonal, somewhat plaited, strigosely pubescent on the outer surface; tube slightly exceeding the calyx-lobes: stamens inserted at the middle of the corolla-tube: nutlets enclosed by the persistent calyx, about 1 mm. long, hirsute-pubescent. — Collected by Prof. A. Dugès near Guanajuato in 1880 (without number); Dr. Edward Palmer, Southwestern Chihuahua, August to November, 1885, nos. 31, 98; Rev. Lucius C. Smith at Cuicatlan, Oaxaca, altitude 554 m., 24 September, 1894, no. 209, and at Las Sedas, altitude 1780 m., 27 June, 1895, no. 391; C. Alvarez, Valley of Elta, Oaxaca, September, 1895 (L. C. Smith's collection), no. 750; Dr. Edward Palmer on Iron Mountain near the city of Durango, June, 1897, no. 141; and by C. G. Pringle on hills near Oaxaca, altitude 1700 m., 2 July, 1897, no. 6726.

A species related to *H. fruticosum*, L., and to which some of the above cited specimens have been referred, but from which it is distinguished by the reflexed pubescence in the stems and branches, the two kinds of pubescence on the leaves, and finally by the shorter flowers and more obtuse calyx-divisions. From *H. rugosum*, Mart. & Gal., it may be distinguished by the pubescent fruit, and foliar characters. Through the kindness of M. Casimir DeCandolle, to whom I am very deeply grateful for many comparisons with type material, our plant was compared with *H. Oaxacanum*, DC., from which species it is amply distinct in the form of the leaves, pubescence, and calyx.

Ægiphila pacifica. Shrub 2.5 to 7 m. high: stems and branches terete, covered with a grayish brown bark and dotted here and there with lenticels, glabrous: branchlets terete, somewhat compressed at the nodes, fulvous-pubescent: leaves opposite, oblong-ovate, 5 to 15 cm. long, 3.5 to 7.5 cm. broad, more or less acuminate, entire, rounded or rather abruptly narrowed at the slightly unequal base, glabrous or at least glabrate above, with scattered tawny subappressed hairs beneath especially upon the midrib and veins: petioles less than 1 cm. in length: inflorescence terminating the stems and branches in rather close paniculate cymes; peduncles, pedicels, the subulate bracts and calyx covered by a fulvous subappressed pubescence: calyx about 4 mm. long, 4-lobed; lobes broader than long, submucronate, greenish: corolla tubular, 10 to 12 mm. long, glabrous; tube somewhat ampliated above; lobes oblong-elliptic, about 4 mm. long, obtuse: stamens equal or rarely unequal, exserted; filaments pubescent below, glabrous above: drupe yellow, obovoid, 8 to 10 mm. long, 6 to 8 mm. in diameter, one half or more exserted from the persistent coriaceous subcrenately lobed, cup-shaped calyx. — Collected by E. W. Nelson, on Maria Madre Island of the Tres Marias group of islands, 3-25 May, 1897, no. 4245 (in flower), and no. 4254 (in fruit).

A species related apparently to *Ægiphila brachiata*, Cham. & Schlecht., but Mr. Nelson's plant certainly does not accord with the description of this species as to the character of the pubescence and the color of the flowers.

SALVIA ALIENA, Greene, Pittonia, i. 157. Excellent specimens of this very well marked species of *Salvia* were secured by Mr. E. W. Nelson on Maria Madre Island of the Tres Marias group of islands, 3–25 May, 1897, no. 4247. Mr. Nelson states that the plant is an herb from

9 to 12 dm. high. The closely and incisely toothed leaves, the rather small blue flowers, a little over 13 mm. in length, render this species readily recognizable.

SOLANUM MARGINATUM, L. f. Suppl. 147. Complete specimens agreeing in every detail with this interesting Old World species were collected by Mr. C. G. Pringle in the Valley of Mexico, 23 August, 1896, no. 7336, and at Contreras, Valley of Mexico, altitude 2400 m., 14 August, 1897, no. 6667; also by Professor A. Dugès, in "Ravin (cañada) de Esperanza à 6 km. de Guanajuato" in the summer of 1897. The species is well illustrated in Jacq. Ic. Rar. t. 45.

Datura pruinosa. Herbaceous: stems, at least above, covered with a fine short close pubescence: leaves ovate or ovate-oblong, 3 to 8 cm. long, one half to two thirds as broad, repand-dentate, acute or obtusish at the apex, unequal at the base, puberulent on the upper surface, pruinose-pubescent beneath: petioles 1 to 4 cm. long, pubescent: flowers erect, pedicellate: pedicels during anthesis 4 to 8 mm. long, later becoming slightly elongated and reflexed: calyx tubular, 5-lobed, 3 to 4 cm. long, densely pubescent especially toward the base; lobes ovate-lanceolate, acute, somewhat unequal: corolla white, 5 to 6 cm. long, glabrous or nearly so; lobes tipped with a slender acumination: stamens included; filaments glabrous, adnate to the corolla-tube for one half its length: capsule pendulent on the reflexed pedicels, subglobose or slightly ovate-oblong, about 3 cm. long, armed with short slender prickles, these as well as the surface of the capsule finely pubescent: seeds oblique, light brown, pitted. — Collected by Rev. Lucius C. Smith, Cuicatlan, Oaxaca, altitude 550 m., 16 October, 1894, and 7 October, 1895, no. 943; also by C. G. Pringle, Valley of Oaxaca, altitude 1540 m., 8 July, 1897, no. 6732. A species readily recognized by the small flowers, and the fine close pruinose pubescence of the young leaves and the tips of the young branches. Most nearly related to *D. Metel*, L.

Distictis laxiflora. *Pithecoctenium laxiflorum*, DC. Prodr. ix. 195. Having at hand numerous and perfect specimens of the above species, it is evident, from the fruiting characters, that its affinity is with the genus *Distictis* rather than *Pithecoctenium*. To DeCandolle's excellent description, drawn, however, from a flowering specimen only, may be appended the following: — climbing: flowers, even in the same specimen, from 4 to nearly 10 cm. long, purple or violet: capsules ovate-oblong or lance-oblong, narrowed at either end, in the dried state 7 to 9 cm. long, about 4 cm. broad, often slightly curved, smooth, glabrate, longitudinally ridged along the midrib and margins of the valves, marginicidally septifragal, the valves falling away from the replum; seeds in several (4 or more) rows. — Collected by Professor A. Dugès, Guanajuato, 1893–1894, no. 111; Mrs. D. H. Sheldon, Lilos, Guanajuato, April, 1893, no. 52; Rev. Lucius C. Smith at Jayacatlan, Oaxaca, 3 June, 1894, no. 16, and at Monte Alban, altitude 1840 m., 26 July, and in November, 1894, no. 148; C. G. Pringle, Monte Alban, altitude 1780 m., 23 November, 1894, no. 5836, and in the same locality, July 1897, no. 6724; Rev. Lucius C. Smith, El Parin, Oaxaca, 15–17 June, 1895, and in October, 1894, no. 445; C. Conzatti and V. González, San Martin, Etla, Oaxaca, altitude 1800 m., 13 June and 8 August, 1897, no. 308. Said to be a "wonderfully beautiful climber with royal purple flowers."

Distictis cinerea. *Pithecoctenium cinereum*, DC. Prodr. ix. 195. Although only flowering specimens of this species are at hand, I have no hesitation in transferring it to the genus *Distictis* as its affinity is clearly with *D. laxiflora* and *D. gnaphalantha*. *D. cinerea* differs from *D. laxiflora* by the more ovate or oval character of the leaflets and the more dense cinereous pubescence on leaves and branches. — To this species may be referred specimens collected by E. W. Nelson near Tamazulapam, altitude 2000 to 2150 m., 16 November, 1894, no. 1958. M. Casimir DeCandolle has very kindly identified this as well as the preceding species with the types in the DeCandolle Herbarium at Geneva.

DISTICTIS GNAPHALANTHA, Benth. & Hook. f. Gen. ii. 1038. To this species may be referred specimens collected by Mr. Robert Combs at Calicita, Cuba, 31 May, 1895, no. 106, distributed under *Bignonia gnaphalantha*, Rich.

DYSCHORISTE QUADRANGULARIS, O. Kuntze, Rev. Gen. Pl. ii. 486. *Calophanes quadrangularis*, Oerst., Vidensk. Meddel. 1854, 120. It is interesting to note that this apparently rare plant has been collected at Las Canoas, State of San Luis Potosi, 29 August, 1891, Pringle, no. 5020. Mr. Pringle's plant hitherto having been confused with *D. bilabiatus*, O. Kuntze, l. c. (*Calophanes bilabiatus*, Seem.), from which species, however, it is readily distinguished by the smaller flowers, and by the absence of a glandular pubescence.

BELOPERONE COMOSA, Nees in DC. Prodr. xi. 416; Hemsl. Biol. Cent.-Am. Bot. ii. 516. *B. Pringlei*, Wats. Proc. Am. Acad. xxv. 160. The type of Dr. Watson's *B. Pringlei*, upon careful comparison with an authentic specimen of the above species collected at Monterey by Dr. Edwards, shows an exact correspondence in every regard, and it also agrees well with the original description. It therefore seems best to regard *B. Pringlei*, Wats., as synonymous with *B. comosa*, Nees.

To this species also may be referred Dr. Coulter's no. 1193; and Pringle's plant, collected in Tamasopa Cañon, State of San Luis Potosi, 10 June, 1890, no. 3074, distributed as *B. Pringlei*, Wats.

Beloperone Nelsonii. Erect: stems branching, subterete, covered with a spreading or slightly reflexed grayish pubescence: leaves ovate-lanceolate or oblong-lanceolate, 5 to 10 cm. long, 2 to 4 cm. broad, obtuse at the apex, entire, narrowed below into a slender petiole, densely lineolate above, pubescent on either surface, especially on the veins, later becoming glabrous; petioles about 2 cm. in length: inflorescence terminating the stem and branches in rather close bracteate spikes: bracts oblong or obovate: bracteoles linear, nearly 1 cm. long, exceeding the calyx: calyx about 5 mm. long, deeply 5-parted; divisions nearly equal, lanceolate, acute, ciliate: corolla 2 to 2.5 cm. long; tube exceeding the limb; upper lip shortly 2-lobed, the lower more deeply 3-lobed, rather broad, somewhat plaited in the throat: capsule 10 to 12 mm. long, pubescent. — Collected by E. W. Nelson on Maria Madre Island of the Tres Marias group of islands, 3–25 May, 1897, no. 4246.

A species closely resembling *B. comosa*, Nees, but with a much shorter corolla, and broader lower lip. The leaves are also somewhat larger, longer petioled and much less pubescent. It may be that further material will prove this to be a variety of *B. comosa*, Nees, but, as the material at hand shows no sign of intergradation, it seems best for the present at least to regard Mr. Nelson's plant as a distinct species.

PORTLANDIA PTEROSPERMA, Wats. Proc. Am. Acad. xxiv. 52. Excellent fruiting specimens were collected by Mr. E. W. Nelson on Maria Madre Island, 3–25 May, 1897, no. 4211, but for the slightly thicker leaves, correspond accurately with the type of the above species. Mr. Nelson's specimens show well the oblong-obovoid longitudinally ribbed and conspicuously lenticulated septicidally dehiscent (2.5 cm. long) capsule.

Machaonia floribunda. Shrub or small tree, 3 to 5 m. high: branches covered with a reddish brown bark, and dotted with numerous small lenticels: the ultimate branches finely pubescent: leaves petiolate, ovate to ovate-lanceolate, 2 to 5 cm. long, 1 to 2 cm. broad, acuminate, acute, entire, ciliate-scabrous, narrowed below into a pubescent petiole (2 to 5 mm. long), glabrous or puberulent on the upper surface, below glabrous except on the midrib toward the base: stipules (1 or 2) linear-subulate, 2 to 3 mm. long: inflorescence of compound many flowered rather closely appressed-pubescent cymes: bracts and bractlets linear-subulate: flowers 4-merous: calyx-tube densely covered with a white appressed pubescence; lobes subequal, about 1 mm. long, obtuse, ciliate: corolla white, 3 mm. long, villous-pubescent on the throat and on the tube: fruit not seen. — Collected by C. G. Pringle on hills near Tampico, 16 June, 1897, no. 6641.

Lobelia tarsophora, Seaton in Mss. Stem erect, simple or branched at the base, 3 to 4.5 dm. high: leaves petiolate, membranaceous, ovate-lanceolate, acuminate, unequal and oblique at the base, undulate and mucronate-denticulate, nearly smooth, 5 to 7.5 cm. long, 2.5 cm. broad. racemes long, loosely flowered: bracts 2 mm. in length: pedicels 10 to 16 mm. long, spreading, becoming horizontal in fruit: corolla blue and white, 4 to 5 mm. in length, the lips unequal: calyx-tube becoming hemispherical in fruit, its rim and ribs persisting after the dehiscence and fall of the small globose half inferior capsule. — Collected by Henry E. Seaton on river banks near Cordoba, altitude 830 m., 20 August, 1891, no. 417. This species is well marked by its foliage, horizontal pedicels, and the peculiar persistence of the rim and nerves of the calyx-tube as a basket-like frame after the dehiscence of the capsule. In habit it most nearly resembles *L. novella*, Rob.

Zexmenia Pringlei. Perennial, stems striate, covered with an arachnoid pubescence: lower leaves opposite, the upper alternate, short-petiolate, ovate, 1.5 to 3 cm. long, two thirds as broad, obtuse at the apex, subcordate at the base, rugose and appressed-tuberculate-hispid above, densely tomentose beneath; petioles 4 to 7 mm. long, narrowly winged; heads including the rays 3 cm. broad, terminating the stem and branches, usually on long peduncles: involucre about 3-seriate; outer scales foliaceous, the inner straw-colored, oblong to oblong-lanceolate, about 1 cm. long, acutish, distinctly 1-nerved, glabrous or nearly so on either surface, long-ciliate on the erose margins toward the apex: pales lance-attenuate, about equalling the flowers, somewhat hirtellous on the distinct keel: ray-flowers 1-seriate, rather numerous (about eighteen); rays oblong, 12 mm. long, nearly one half as broad; akenes triangular becoming somewhat verrucose at maturity: disk-flowers about 1 cm. long; pappus bisetose with minute intermediate scales; mature akenes laterally compressed, with a narrow ciliated cartilaginous wing, glabrous or a little roughened, about 4 mm. long. — Collected by C. G. Pringle on limestone hills near Tehuacan, altitude 2000 m., 5 August, 1897, no. 6768.

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NOTE ON THE PROJECTIVE GROUP.

By E. W. Rettger.

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Presented by Henry Taber, April 13, 1898.

The general projective group occupies a position of special importance in Lie's theory of finite continuous groups. For associated with any finite continuous group G_r with r parameters is a sub-group with $\rho \leqq r-1$ parameters of the general projective group in $(r-1)$-fold space, the knowledge of whose invariants (general and special) enables us to enumerate the different types of sub-groups of G_r. This projective group is obtained from the adjoined group of G_r by regarding the variables in the equations of transformation of the adjoined as homogeneous co-ordinates.

Lie showed that the general projective group is continuous, in the sense that each transformation of this group can be generated by an infinitesimal transformation of the group.* But Professor Study made the important discovery that not every transformation of the special linear homogeneous group can be generated by an infinitesimal transformation of the special linear homogeneous group; † and thus showed that the sub-groups of the general projective group are not all continuous in the sense in which this term is here employed: namely, a group is here termed continuous if each transformation of the group can be generated by an infinitesimal transformation of the group, and therefore belongs to a continuous one-term sub-group of the group in question.

Subsequently Professor Taber showed that not every transformation of the orthogonal group in n variables, for $n \geqq 4$, can be generated by an infinitesimal transformation of this group, and established equivalent results for the group of automorphic linear transformations of an alternate bilinear form, and for the group of automorphic linear transformations of a general bilinear form.‡ I have found, moreover, that a number of the sub-groups of the projective group in two and three variables are not properly continuous, except in the neighborhood of the identical transformation. These groups are enumerated at the end of this paper.

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* Lie, *Continuierliche Gruppen*, p. 45.

† *Leipzige Berichte*, 1892.

‡ *Bull. N. Y. Math. Society*, July, 1894; *Math. Ann.*, Vol. XLVI. p. 561; *Math. Review*, Vol. I. p. 154.

In what follows I deal with a consequence of Study's discovery which I believe has not yet been touched upon. I shall term a transformation of a so called continuous group that cannot be generated by an infinitesimal transformation of this group a *singular transformation* of this group.

Let $\mathbf{G}_\rho$ denote a projective group in n-fold space. Two points, p and p_1, of general position on the same invariant manifold relative to $\mathbf{G}_\rho$ can always be interchanged by one or more transformations of $\mathbf{G}_\rho$. In general, each of the transformations by which p and p_1 are interchanged can be generated by an infinitesimal transformation of $\mathbf{G}_\rho$: in which case I shall say that the points p and p_1 can be continuously interchanged by the transformations of this group. But, if $\mathbf{G}_\rho$ contains singular transformations, it sometimes happens that the points p and p_1 cannot be interchanged by a transformation of $\mathbf{G}_\rho$ that can be generated by an infinitesimal transformation of $\mathbf{G}_\rho$; and, in this case, I shall say that the points p and p_1 cannot be continuously interchanged.

If now $n = r - 1$, and $\mathbf{G}_\rho$ is the projective group above referred to, associated with an r-term group G_r, then every point in the space S_{r-1} to which the transformations of $\mathbf{G}_\rho$ are applied represents a one-term group of G_r. And two points, p and p_1, of general position on the same invariant manifold in S_{r-1}, relative to $\mathbf{G}_\rho$, represent one-term groups of G_r of the same type, since they can be interchanged by transformations of $\mathbf{G}_\rho$. If, however, p and p_1 cannot be continuously interchanged by the transformations of $\mathbf{G}_\rho$, i. e. interchanged by a transformation generated by an infinitesimal transformation of $\mathbf{G}_\rho$, the one-term groups of G_r represented by these points, although of the same type, are differently related from two one-term groups of G_r represented by two points of S_{r-1} that can be interchanged continuously by the transformations of $\mathbf{G}_\rho$, i. e. interchanged by a transformation generated by an infinitesimal transformation of $\mathbf{G}_\rho$.

If the smallest invariant manifold relative to any ρ-term projective group $\mathbf{G}_\rho$ is q-way extended, $q \leqq \rho$, then there are $\infty^{\rho - q}$ transformations of $\mathbf{G}_\rho$ that will interchange two points, p and p_1, of general position on any invariant manifold relative to $\mathbf{G}_\rho$. If $\rho = q$, then there is but *one* transformation.[*] If this transformation is singular, that is, if this transformation cannot be generated by an infinitesimal transformation of $\mathbf{G}_\rho$, then, clearly, not all points on each smallest invariant manifold can be continuously interchanged; and, therefore, the one-term sub-groups of G_r represented by these points, if $\mathbf{G}_\rho$ is the projective group associated with G_r, cannot all be transformed into one another continuously by means of the transformation of $\mathbf{G}_\rho$. But, if $q < \rho$, then it is by no means certain, when $\mathbf{G}_\rho$ contains singular transformations, that p and p_1 can be chosen so that all the $\infty^{\rho - q}$ transformations are singular. In fact, in all cases I have considered this is never possible. It may happen that but one or all but one of the $\infty^{\rho - q}$ transformations are singular. In this case the points of general position on any smallest invariant manifold can be continuously interchanged by means of the transformation of the given group, although the group contain transformations that cannot be generated by an infinitesimal transformation of the group.

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[*] Lie, *Continuierliche Gruppen*, p. 432.

I have examined all the two and three-term groups enumerated by Lie in the *Continuierliche Gruppen*, pp. 288 and 519. In each case the associated (adjoined) projective group $\mathbf{G}_\rho$ is such that two points of general position on the smallest invariant manifold relative to $\mathbf{G}_\rho$ can always be interchanged continuously, notwithstanding that in certain cases the associated group $\mathbf{G}_\rho$ contains singular transformations. I have therefore, as yet, found no group G_r whose one-term sub-groups of the same type cannot all be continuously interchanged by the transformations of the adjoined projective group. But it seems probable that such groups G_r exist.

The following examples illustrate the effect of the existence of singular transformations among the transformations of a projective group $\mathbf{G}_\rho$ upon the interchange, by transformations of $\mathbf{G}_\rho$, of points on the same invariant manifold relative to $\mathbf{G}_\rho$. They have been selected from the list given at the end of this paper. The third group considered is the adjoined group of a number of three-term projective groups.

Example 1. Consider the two-term projection group of the plane,

$$xq, \quad xp + 3yq.$$

The symbol of infinitesimal transformation is

$$c_1 xq + c_2 (xp + 3yq);$$

and the ∞^2 of finite transformations T_c generated by ∞^1 of infinitesimal transformations are of the form,

$$x' = e^{c_2} x_3 ,$$
$$y' = \frac{c_1}{2\,c_2}\,(e^{3c_2} - e^{c_1})\,x + e^{3c_2}\,y.$$

The group contains singular transformations T which are of the form,

$$x' = -x,$$
$$y' = Nx - y \quad (N \pm 0).$$

Now T applied to a point p on the line $x = +c$ will transform p to a point p_1 on the line $x = -c$; and, clearly, there is no non-singular transformation T_c among the transformations of the group that has the same effect. If the singular transformation T is applied to a point on the special invariant $x = 0$, p will be conveyed across the invariant point $x = 0$, $y = 0$. But this can be done by a non-singular transformation whose path curve is imaginary; for this transformation may be effected by the non-singular transformation

$$x' = -x,$$
$$y' = -y.$$

Therefore, two points, p and p_1, in the plane that lie on opposite sides of, and equidistant from, the special invariant $x = 0$ cannot *always* be interchanged among themselves continuously by means of the tranformations of the group.

Example 2.

$$x_3 p_2, \;\; x_1 p_2, \;\; x_1 p_1 + 2\,x_2 p_2.$$

The ∞^3 of non-singular transformations T_c have the form,

$$x'_1 = e^{c_3} x_1 ,$$
$$x'_2 = \frac{c_2}{c_3}\,(e^{2c_2} - e^{c_3})\,x_1 + e^{2c_3} x_2 + \frac{c_1}{2\,c^3_3}\,(e^{2c_3} - 1)\,x_3 .$$
$$x'_3 = x_3 ;$$

and the ∞^2 of singular transformation T have the form,

$$x'_1 = -x_1 ,$$
$$x'_2 = Mx_1 + x_2 + Nx_3 , \quad (N \pm 0)$$
$$x'_3 = x_3 .$$

A ∞^1 of the singular transformations T will move a given point p of general position on the line $x_1 = + c$, $x_3 = k$, to a given point p_1 of general position on the line $x_1 = - c$, $x_3 = k$. Nevertheless, we can find one non-singular transformation that will do the same, namely,

$$\begin{aligned} x'_1 &= - x_1 , \\ x'_2 &= A x_1 + x_2 , \\ x'_3 &= x_3 . \end{aligned}$$

For clearly, by a proper choice of A, this transformation T_c has the same effect when applied to a definite given point as the transformation T for any given values of M and N $(N \neq 0)$.

Example 3.

$$x_3 p_1 , \quad x_3 p_2 , \quad x_1 p_1 + 2 x_2 p_2 .$$

The ∞^3 of non-singular transformations T_c have the form,

$$\begin{aligned} x'_1 &= e^{c_3} x_1 + \frac{c_1}{c_3} (e^{c_3} - 1) x_3 , \\ x'_2 &= e^{2c_3} x_2 + \frac{c_2}{2 c_3} (e^{2c_3} - 1) x_3 , \\ x'_3 &= x_3 . \end{aligned}$$

The ∞^2 of singular transformations have the form,

$$\begin{aligned} x'_1 &= - x_1 + M x_3 , \\ x'_2 &= x_2 + N x_3 , \quad (N \neq 0) \\ x'_3 &= x_3 . \end{aligned}$$

By means of the latter a given point p of general position on the plane $x_3 = k$ can be transformed into a given point p_1 of general position in that plane. But it is easily seen that c_1, c_2, and c_3 of T_c can be chosen in ∞^1 of ways so that T_c will produce the same effect.

Example 4.

$$x_3 p_1 , \quad x_3 p_2 , \quad 2 x_1 p_2 + 3 x_2 p_2 + x_3 p_3 .$$

The ∞^3 of non-singular transformations T_c have the form,

$$x'_1 = e^{2c_3} x_1 + \frac{c_1}{c_3} (e^{2c_3} - e^{c_3}) x_3 ,$$

$$\begin{aligned} x'_2 &= e^{3c_3}x_2 + \frac{c_2}{2\,c_3}\left(e^{3c_3} - e^{c_3}\right)x_3\,, \\ x'_3 &= e^{c_3}x_3\,. \end{aligned}$$

The ∞^2 of singular transformations T have the form,

$$\begin{aligned} x'_1 &= x_1 + Mx_3\,, \\ x'_2 &= -x_2 + Nx_3\,, \quad (N \pm 0) \\ x'_3 &= -x_3\,. \end{aligned}$$

The transformation T, if we regard x_1, x_2, x_3 as Cartesian co-ordinates, will convey a given point p of general position in the plane $x_3 = +c$ to a point p_1 on the plane $x_3 = -c$; and clearly there is no other transformation of the group that will do the same. The points on the special invariant $x_3 = 0$ can be continuously interchanged, for the transformation effected by T can also be effected by the non-singular transformation,

$$\begin{aligned} x'_1 &= x_1 + Ax_3\,, \\ x'_2 &= -x_2\,, \\ x'_3 &= -x_3\,. \end{aligned}$$

Therefore, in this group, points on opposite sides of, and equidistant from, the special invariant $x_3 = 0$ cannot *all* be interchanged continuously among themselves.

The following groups enumerated by Lie on pp. 288 and 519 of his *Continuierliche Gruppen* are not properly continuous except in the neighborhood of the identical transformation.

$$\boxed{q,\quad p + xq,\quad xp + 2yq} \qquad \boxed{q,\quad xq,\quad p + yq}$$

$$\boxed{p,\quad q,\quad xp + (y - x)q} \qquad \boxed{xq,\quad xp - yq,\quad yp}$$

$$\boxed{p,\quad q,\quad (a - 1)xp + ayq} \qquad \boxed{q,\quad xq,\quad xp + ayq}$$

$$\boxed{q,\quad yq + p} \qquad \boxed{xq,\quad xp + q}$$

$$\boxed{xq,\quad xp + ayq\;(a \pm 0,\ 1)}$$

$$\boxed{x_3 p_2 , \quad x_3 p_1 + x_1 p_2 , \quad x_2 p_2 - x_3 p_3 + \beta U}$$

$$\boxed{x_3 p_2 , \quad x_1 p_2 , \quad x_3 p_1 + x_2 p_2 + \beta U}$$

$$\boxed{x_3 p_1 , \quad x_3 p_2 , \quad x_1 p_1 + x_1 p_2 + x_2 p_2 + \beta U}$$

$$\boxed{x_1 p_2 , \quad x_1 p_1 - x_2 p_2 , \quad x_2 p_1}$$

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Proceedings of the American Academy of Arts and Sciences.

Vol. XXXIII. No. 27. — July, 1898.

PROCEEDINGS OF THE ACADEMY, 1897-1898.

REPORT OF THE COUNCIL: BIOGRAPHICAL NOTICES.

Benjamin Eddy Cotting. By David W. Cheever.

Alvan Graham Clark. By Oliver C. Wendell.

Alonzo Smith Kimball. By T. C. Mendenhall.

LIST OF THE FELLOWS AND FOREIGN HONORARY MEMBERS.

STATUTES AND STANDING VOTES.

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(Title Page and Table of Contents.)

PROCEEDINGS.

Eight hundred and ninety-first Meeting.

May 12, 1897. — ANNUAL MEETING.

The Academy met at the Jefferson Physical Laboratory of Harvard College, Cambridge.

The PRESIDENT in the chair.

The chair announced the death of Matthew Carey Lea, of Philadelphia, Associate Fellow.

The Corresponding Secretary read letters from Ludwig Boltzmann, Wilhelm Dörpfeld, and W. Pfeffer, acknowledging their election as Foreign Honorary Members; also a circular from the Academy of Natural Sciences of Philadelphia, calling attention to a proposed amendment to the regulations governing the mails of the Universal Postal Union.

The Corresponding Secretary read the Report of the Council.*

The Treasurer presented his annual report, of which the following is an abstract: —

GENERAL FUND.

Receipts.

Balance, May 1st, 1896			$2,115.68
Assessments	$920.00		
Sale of publications	163.62	$1,083.62	
Income from investments		4,718.21	
Return of bank tax		41.18	
Donations		105.00	5,948.01
			$8,063.69

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* See Proceedings, Vol. XXXII. p. 331.

Expenditures.

General expenses	$2,027.75	
Publishing expenses	2,599.62	
Library expenses	1,475.09	$6,101.96
Balance, May 1st, 1897		1,961.73
		$8,063.69

RUMFORD FUND.

Receipts.

Balance, May 1st, 1896		$1,908.33
Income	$2,576.41	
Return of bank tax	96.08	2,672.49
		$4,580.82

Expenditures.

Books and binding	$53.22	
Publishing expenses	883.94	
Investigations	500.00	
Rent	10.00	$1,447.16
Balance, May 1st, 1897		3,133.66
		$4,580.82

WARREN FUND.

Receipts.

Balance, May 1st, 1896	$614.89
Income	856.06
	$1,470.95

Expenditures.

Investigations	$600.00
Balance, May 1st, 1897	870.95
	$1,470.95

BUILDING FUND.

Receipts.

Balance, May 1st, 1896	$288.68
Income	485.10
	$773.78
Balance, May 1st, 1897	$773.78

The Librarian presented his annual report, of which the following is an abstract: — 3,329 books and pamphlets have been added to the Library during the past year, 2,429 of which were obtained by gift and exchange, 687 purchased with the appropriation from the income of the General Fund, at a cost of $334.98, and 213 with the appropriation from the income of the Rumford Fund, at a cost of $23.92. During the year, 561 volumes were bound at an expense of $620.10, of which $26.80 was charged to the Rumford Fund. The total expenditure for books, periodicals, and binding amounted to $979.00 of which $50.72 was charged to the Rumford Fund. 180 books were borrowed from the Library by 31 persons, 20 of whom were Fellows of the Academy.

The following reports were also presented: —

REPORT OF THE RUMFORD COMMITTEE.

At a meeting, October 26, 1896, the Committee voted that the sum of $400 be put at the disposal of Professor Henry Crew, of Northwestern University, for investigations on the electrical, chemical, and thermal effects of the electric arc.

The sum of $100 was also voted to Mr. R. O. King, for investigations on the Thomson effect in metals.

JOHN TROWBRIDGE, *Chairman.*

May 12, 1897.

REPORT OF THE C. M. WARREN COMMITTEE.

In behalf of the C. M. Warren Committee I have to report that during the past year a grant of six hundred dollars ($600) has been made to Professor C. F. Mabery, of Cleveland, Ohio, in aid of his investigations of the chemistry of petroleum; and a grant of two hundred dollars ($200) to Professor H. O. Hofman, of Boston, in aid of his investigation of the formation-temperatures of certain silica-iron-lime slags of metallurgical importance.

I have received from Professor F. C. Phillips a highly satisfactory "report of progress" concerning his researches on natural gas, in behalf of which a grant was made by the Academy year before last.

Professor Mabery's researches on petroleum have gone on steadily during the year, and several important papers relating to them have been published by him.

F. H. STORER, *Chairman.*

REPORT OF THE COMMITTEE OF PUBLICATION.

During the past year two numbers of Vol. XII. of the Memoirs have been published, aggregating 296 pages and 26 plates, as well as the whole of Vol. XXXI. and fourteen numbers of Vol. XXXII. of the Proceedings aggregating 674 pages and 1 plate.

One Memoir and eight papers in the Proceedings have been paid for from the Rumford Fund, and two papers appeared in Vol. XXXI. of the Proceedings, at no cost to the Academy. From the Academy's general funds there have been expended $1,131.89 for Memoirs, and $1,467.73 for Proceedings, a total of $2599.62.

In May last the Academy appropriated from its general funds the sum of $2,300 for publications; at the December meeting there was added to this the sum of $461 (the direct subscription the previous year for the publication of Vol. XXXI. of the Proceedings), together with the proceeds from the sales of publications during the year, which have amounted to $163.62, giving a total appropriation of $2,924.62, and leaving an unexpended balance of $325.

The Committee hopes that to the usual annual appropriation of $1,800 this sum of $325 may be added.

A change has been made in the mode of publication of the Proceedings which insures a more prompt issue without adding to their cost.

SAMUEL H. SCUDDER,
Chairman.

On the recommendation of the Committee of Finance, it was

Voted, To make the following appropriations from the income of the General Fund for the ensuing year:

For general expenses	$2,000.00
For the Library	1,400,00
For publications	2,100,00

Voted, That the assessment for the ensuing year be five dollars.

Voted, That one thousand dollars ($1,000) from the income of the Rumford Fund be placed at the disposal of the Rumford Committee, to be expended in aid of investigations on Light and Heat, payments to be made on the order of the Chairman of the Committee.

On the recommendation of the C. M. Warren Committee it was

Voted, That the sum of six hundred dollars ($600) from the income of the C. M. Warren Fund be granted to Professor C. F. Mabery of Cleveland, Ohio, to aid him in continuing his researches on the chemistry of petroleum.

The Chair announced that H. E. Scudder and Roland Thaxter had asked to have their nominations for the Council withdrawn.

The annual election resulted in the choice of the following officers and committees: —

ALEXANDER AGASSIZ, *President.*
JOHN TROWBRIDGE, *Vice-President for Class I.*
GEORGE L. GOODALE, *Vice-President for Class II.*
AUGUSTUS LOWELL, *Vice-President for Class III.*
SAMUEL H. SCUDDER, *Corresponding Secretary.*
WILLIAM WATSON, *Recording Secretary.*
ELIOT C. CLARKE, *Treasurer.*
HENRY W. HAYNES, *Librarian.*

Councillors.

HENRY MITCHELL, LEONARD P. KINNICUTT, EDWARD H. HALL,	of Class I.
HENRY P. BOWDITCH, WILLIAM M. DAVIS, BENJAMIN L. ROBINSON,	of Class II.
JOHN E. HUDSON, BARRETT WENDELL, EDWARD ROBINSON,	of Class III.

Member of the Committee of Finance.

AUGUSTUS LOWELL.

Rumford Committee.

ERASMUS D. LEAVITT, AMOS E. DOLBEAR,
EDWARD C. PICKERING, ARTHUR G. WEBSTER,
CHARLES R. CROSS, THEODORE W. RICHARDS,
THOMAS C. MENDENHALL.

C. M. Warren Committee.

FRANCIS H. STORER,	HENRY W. HILL,
CHARLES L. JACKSON,	LEONARD P. KINNICUTT,
SAMUEL CABOT,	ARTHUR M. COMEY,

ROBERT H. RICHARDS.

The following gentlemen were elected members of the Academy: —

Harry Manley Goodwin, of Boston, to be a Resident Fellow in Class I., Section 2 (Physics).

Frank Arthur Laws, of Boston, to be a Resident Fellow in Class I., Section 2.

Walter Lewis Jennings, of Worcester, to be a Resident Fellow in Class I., Section 3 (Chemistry).

Abbott Lawrence Lowell, of Boston, to be a Resident Fellow in Class III., Section 3 (Political Economy and History).

William Osler, of Baltimore, to be an Associate Fellow in Class II., Section 4 (Medicine and Surgery), in place of the late Henry Newell Martin.

William Henry Welch, of Baltimore, to be an Associate Fellow in Class II., Section 4.

Horace Howard Furness, of Philadelphia, to be an Associate Fellow in Class III., Section 4 (Literature and the Fine Arts).

Edmund Clarence Stedman, of New York, to be an Associate Fellow in Class III., Section 4.

Percival Lowell gave an account of some "New Observations of the Planet Mercury."

The following papers were presented by title: —

On the Locus that represents an Automorphic Linear Transformation of a Bilinear Form. By William E. Story and Henry Taber.

Studies on the Central and Peripheral Nervous Systems of two Polychæte Annelids. By Margaret Lewis. Presented by E. L. Mark.

On the Temperature Coefficient of the Potential of the Calomel Electrode, with several different Supernatant Electrolytes. By T. W. Richards.

Note on the Rate of Dehydration of Crystallized Salts. By T. W. Richards.

On the 3, 4, 5 Tribromaniline and some Derivatives of unsymmetrical Tribrombenzol. By C. Loring Jackson and F. B. Gallivan.

On the Oxide of Dichlormethoxyquinonedibenzoylmethylacetal. By C. Loring Jackson and H. A. Torrey.

Eight hundred and ninety-second Meeting.

June 9, 1897.

The Academy met at the house of Francis Blake, at Weston.

The President in the chair.

The Chair announced the death of Alvan Graham Clark, Benjamin Eddy Cotting, and John Lowell, Resident Fellows.

The Chair read a letter from the Boston Society of Natural History in reference to inviting the American Association for the Advancement of Science to meet in Boston in 1898. This matter was referred to the executive officers.

The following papers were read: —

Certain Considerations concerning the Coinage of the Colony and the Public Bills of Credit of the Province of the Massachusetts Bay. By A. McFarland Davis.

Suggestions for the Development of the Arts and Sciences. By William R. Livermore.

The following papers were presented by title: —

The Orthopteran Group Scudderiæ. By S. H. Scudder.

Contributions from the Gray Herbarium of Harvard University. New Series. No. XII. — By M. L. Fernald. I. A Systematic Study of the United States and Mexican Species of Pectis. II. Some rare and undescribed Plants collected by Dr. Edward Palmer at Acapulco, Mexico. Presented by B. L. Robinson.

A Revision of the Atomic Weight of Cobalt. By T. W. Richards and G. P. Baxter.

A Revision of the Atomic Weight of Nickel. By T. W. Richards and A. S. Cushman.

Eight hundred and ninety-third Meeting.

October 13, 1897. — STATED MEETING.

VICE-PRESIDENT TROWBRIDGE in the chair.

The Chair announced the death of Theodore Lyman, Resident Fellow; Alfred Marshall Mayer, James Hammond Trumbull, Associate Fellows; Alfred Louis Olivier Legrand Des Cloizeaux, Victor Meyer, Julius von Sachs, and Johannes Japetus Smith Steenstrup, Foreign Honorary Members.

The Corresponding Secretary read a letter from Henry M. Howe, resigning his fellowship on account of removal to New York.

The following gentlemen were elected members of the Academy: —

James Mills Peirce, of Cambridge, as Resident Fellow in Class I., Section 1 (Mathematics and Astronomy).

Ira Nelson Hollis, of Cambridge, as Resident Fellow in Class I., Section 4 (Technology and Engineering).

Heinrich Brunner, of Berlin, as Foreign Honorary Member in Class III., Section 1 (Philosophy and Jurisprudence).

Frederic William Maitland, of Cambridge, as Foreign Honorary Member in Class III., Section 1.

Georg Morris Cohen Brandes, of Copenhagen, as Foreign Honorary Member in Class III., Section 4 (Literature and the Fine Arts).

Pierre Cécile Puvis de Chavannes, of Paris, as Foreign Honorary Member in Class III., Section 4.

Amos E. Dolbear read a paper entitled "Contrasted Properties of Matter and the Ether." Remarks on this communication were made by W. E. Story and A. G. Webster.

Eight hundred and ninety-fourth Meeting.

November 10, 1897.

In the absence of the regular presiding officers, MORILL WYMAN was chosen President *pro tempore.*

The following letters were received: — from H. M. Goodwin, Ira N. Hollis, and Frank Arthur Laws, accepting Fellowship; from C. H. Fernald, declining Fellowship; from Horace Howard Furness, Edmund C. Stedman, and William H. Welch, acknowledging election as Associate Fellows; also letters announcing the death of Johannes Japetus Smith Steenstrup and Julius von Sachs, Foreign Honorary Members, of Alfred Ritter von Arneth, President of the Imperial Academy of Sciences, Vienna, and of Tommaso Vallauri, Member of the Royal Academy of Sciences, Turin.

On the motion of Eliot C. Clarke, the following resolution was adopted: —

Whereas, The Academy has received from the executors of the estate of John Lowell the sum of three thousand dollars, being a bequest, unrestricted as to its disposition, therefore be it

Resolved, That the Academy accepts said bequest with grateful appreciation of the generosity and trust of its late honored Resident Fellow, and will apply the same to the general purposes of the Academy, and that the Corresponding Secretary notify this action to Judge Lowell's executors.

Theodore Wm. Richards presented a paper on the Atomic Weights. Remarks on this subject were made by Arthur G. Webster.

The following paper was presented by title: —

On the Cuprosammonium Bromides and the Cuprammonium Sulphocyanates. By Theodore Wm. Richards and Benj. S. Merigold.

Eight hundred and ninety-fifth Meeting.

December 8, 1897.

The CORRESPONDING SECRETARY in the chair.

The Chair announced the death of Justin Winsor, Resident Fellow.

Letters were read from J. M. Peirce and F. W. Maitland, acknowledging election into the Academy; and from the Colonial

Society of Massachusetts, thanking the Academy for past courtesies, and requesting the use of its hall for the five stated meetings of the Society during the ensuing year.

On the motion of the Recording Secretary it was

Voted, To grant the request of the Colonial Society.

On the motion of the Treasurer, it was

Voted, That a Committee consisting of Messrs. Trowbridge, H. P. Bowditch, and Livermore be appointed on the part of the Academy to confer with any similar committee appointed on the part of the Massachusetts Historical Society, to ascertain whether the Academy can obtain suitable quarters in the new building of the Historical Society, and upon what terms, and to make any recommendation to the Academy which may seem desirable to said committee.

The following papers were read: —

On a recently discovered Egyptian Inscription relating to Israel. By Crawford H. Toy.

On some Properties of Fourfold Space. By William E. Story.

Eight hundred and ninety-sixth Meeting.

January 12, 1898. — STATED MEETING.

VICE-PRESIDENT TROWBRIDGE in the Chair.

The Chair announced the death of Francesco Brioschi, of Milan, and Don Pascual de Gayangos, of Madrid, Foreign Honorary Members.

The Corresponding Secretary read letters from the Superior Technical Institute of Milan, and the Royal Academy of Lincei of Rome, announcing the death of Francesco Brioschi, Foreign Honorary Member; and from P. Puvis de Chavannes, acknowledging his election as Foreign Honorary Member.

On the motion of the Corresponding Secretary it was

Voted, To meet on adjournment on the second Wednesday in February.

On the recommendation of the Rumford Committee, it was

Voted, To appropriate the sum of four hundred dollars ($400) from the income of the Rumford Fund to W. C. Sabine for investigations in ultra-violet radiation.

On motion of Augustus Lowell it was

Voted, To authorize the Treasurer to make suitable arrangements with the Massachusetts Historical Society, for the accommodation of the Academy in the new building of the Society. It was also

Voted, To grant the free use of the hall of the Academy to the Historical Society for its regular meetings until the completion of the new building.

The following gentlemen were elected members of the Academy: —

George Edward Davenport, of Medford, to be a Resident Fellow in Class II., Section 2 (Botany).

John George Jack, of Boston, to be a Resident Fellow in Class II., Section 2.

John Merle Coulter, of Chicago, to be an Associate Fellow in Class II., Section 2, in place of the late Daniel Cady Eaton.

Douglas Houghton Campbell, of Palo Alto, to be an Associate Fellow in Class II., Section 2.

Elias Metschnikoff, of Paris, to be a Foreign Honorary Member in Class II., Section 3 (Zoölogy and Physiology).

The following papers were presented by title: —

The Thoracic Derivation of the Cardinal Veins in Swine. By G. H. Parker and C. H. Tozier.

The Analysis of the Action of the Vagus Nerve upon the Heart. Preliminary Notice. By L. J. J. Muskens. Presented by H. P. Bowditch.

On the Colored Compounds obtained from Sodic Alcoholates and Picrylchloride. By C. Loring Jackson and W. F. Boos.

The following papers were read: —

Changes in the Proportionate Diameters of the Shells of New England Mollusks. By Edward S. Morse.

A Probable Magnetic Telegraph of the Sixteenth Century. By Samuel Cabot.

On the Source of the X-Rays. By John Trowbridge.

Eight hundred and ninety-seventh Meeting.

February 9, 1898. — ADJOURNED STATED MEETING.

The Academy met at the house of John C. Ropes.

The RECORDING SECRETARY in the chair.

The following papers were read: —

The most recent Babylonian Explorations. By David G. Lyon.

The Seven Days' Battles near Richmond. By John C. Ropes.

Eight hundred and ninety-eighth Meeting.

March 9, 1898. — STATED MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters from George Edward Davenport, Douglas H. Campbell, John M. Coulter, and El. Metschnikoff, acknowledging election into the Academy; and from F. W. Taussig, resigning his Fellowship.

The chair announced the death of Alonzo Smith Kimball, Resident Fellow; William Augustus Rogers, Associate Fellow; and Rudolf Leuckart, Foreign Honorary Member.

The following gentlemen were elected members of the Academy: —

Charles Rockwell Lanman, of Cambridge, to be a Resident Fellow in Class III., Section 2 (Philology and Archæology).

Albert Heim, of Zurich, to be a Foreign Honorary Member in Class II., Section 1 (Geology, Mineralogy, and Physics of the Globe).

Friedrich von Recklinghausen, of Strassburg, to be a Foreign Honorary Member in Class II., Section 4 (Medicine and Surgery).

Ferdinand Brunetière, of Paris, to be a Foreign Honorary Member in Class III., Section 4 (Literature and the Fine Arts).

The President appointed the following Councillors to act as Nominating Committee: —

Leonard P. Kinnicutt, of Class I., William M. Davis, of Class II., and John E. Hudson, of Class III.

On the recommendation of the Rumford Committee, it was

Voted, To appropriate from the income of the Rumford Fund the sum of two hundred and fifty dollars ($250) to Professor A. A. Michelson, of Chicago, for an investigation regarding diffraction gratings. This is in addition to a sum of two hundred and fifty dollars already appropriated by the Rumford Committee from the funds at its own disposal.

The following papers were presented by title: —

Contributions from the Gray Herbarium of Harvard University. New Series. No. XIII. — By B. L. Robinson. I. Revision of the North American and Mexican Species of Mimosa. II. Revision of the North American Species of Neptunia.

An Inquiry into the Nature of Electrical Discharges in Air and Gases. By John Trowbridge.

On the Sources of Luminosity in the Electric Arc. By Henry Crew and Olin H. Basquin. Presented by C. R. Cross.

A Table of Atomic Weights. By Theodore William Richards.

On the Cause of the Retention and Release of Gases occluded by the Oxides of Metals. By Theodore William Richards.

Edward Atkinson read a paper, entitled "The Basis of the Science of Political Economy."

The question of printing a table of atomic weights every year, with T. W. Richards's corrections, was referred to the Committee of Publication.

Eight hundred and ninety-ninth Meeting.

April 13, 1898.

The Academy met at the house of Augustus Lowell.

The President in the chair.

The President announced the death of Sir Henry Bessemer, Foreign Honorary Member.

The following papers were read: —

The Theory of Coral Reefs. By Alexander Agassiz.

Occurrence of Native Copper at Franklin Furnace, New Jersey. By John E. Wolff.

Exhibition and Preliminary Account of a Collection of Microphotographs of Snow Crystals, made by W. A. Bentley. By John E. Wolff.

Albert A. Michelson exhibited and described a new form of spectroscope.

The following papers were read by title: —

Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy: A Contribution to the Study of Individual Variation in the Wings of Lepidoptera. By W. L. W. Field. Certain Sense Organs of the Proboscis of Rhynchobolus dibranchiatus. By A. Oppenheimer. Presented by E. L. Mark.

Contributions from the Gray Herbarium of Harvard University. New Series. No. XIV. — By J. M. Greenman. I. Revision of the Mexican and Central American Species of Galium and Relbunium. II. Diagnoses of New and Critical Mexican Phanerogams. Presented by B. L. Robinson.

An Absolute Measurement of the Thomson Effect in Copper. By R. O. King. Presented by E. H. Hall.

Note on Stokes's Theorem in Curvilinear Co-ordinates. By A. G. Webster.

Note on the Projective Group. By E. W. Rettger. Presented by Henry Taber.

On the Thermal Conductivities of Certain Poor Conductors. By B. O. Peirce and R. W. Willson.

AMERICAN ACADEMY OF ARTS AND SCIENCES.

Report of the Council. — Presented May 11, 1898.

BIOGRAPHICAL NOTICES.

Benjamin Eddy Cotting	By David W. Cheever.
Alvan Graham Clark	Oliver C. Wendell.
Alonzo Smith Kimball	T. C. Mendenhall.

REPORT OF THE COUNCIL.

SINCE the Annual Meeting of May 12, 1897, the Academy has lost by death eighteen members: — seven Resident Fellows, Alvan Graham Clark, Benjamin Eddy Cotting, Alonzo Smith Kimball, John Lowell, Theodore Lyman, Jules Marcou, and Justin Winsor; three Associate Fellows, Alfred Marshall Mayer, William Augustus Rogers, and James Hammond Trumbull; and eight Foreign Honorary Members, Sir Henry Bessemer, Francesco Brioschi, Alfred Louis Olivier Legrand Des Cloiseaux, Pascual de Gayangos, Rudolf Leuckart, Victor Meyer, Julius von Sachs, and Johannes Japetus Smith Steenstrup.

BENJAMIN EDDY COTTING.

OUR late associate, Doctor BENJAMIN EDDY COTTING, enjoyed the rather rare opportunity of serving two Institutions for nearly fifty years. As Curator of the Lowell Institute, he held office for over half a century.

Add to this a professional life of sixty years, of which three-fourths was active, and we have a remarkable record. A calm temperament and continuous health enabled him to do all this with comparative ease to himself, and with benefit to others. He had a happy faculty of throwing off care, of working easily, of taking recreation between work. All of us remember him as a charming host, genial, bright, self-forgetful.

In making and keeping medicine respectable, honest and honorable, no doctor in Massachusetts ever played a more useful part. He might be styled the father, if not the founder, of the Massachusetts Medical Society, and was a financial backer and warm supporter of our local Medical Journal.

It was of great benefit, as well as a pleasure to him, to share the society and to follow the guidance of men of the sciences, other than medical. He enjoyed immensely the position of active patron of the Lowell Lectures. He was very punctual and conscientious in his attendance at the opening of all these courses.

He was a constant attendant at, and an occasional contributor to the meetings of the Academy. He took a keen interest in the practical welfare of the society and of its members.

Dr. Cotting was a sceptic; his habit of mind was negative in belief. This applied to his own medical belief and to all the range of psychical events. He was a good observer, and clear-headed in his views. He was a positivist but not a dogmatist. He had many virtues which are called old-fashioned, and he was obstinate in his convictions.

His benevolence was self-sacrificing, and therein differed from common giving, — in faith nothing, in charity all. Those virtues which were fundamental in the Puritan remained vital in him; they were tempered by great kindness, but never weakened by concession. The frittering attrition of modern luxury and material advancement softens or weakens most characters, — a few, like our deceased brother's, remain sharp, clear-cut, in all time, like the basalt or granite of Egypt.

David W. Cheever.

ALVAN GRAHAM CLARK.

In St. Paul's cathedral is a simple tablet, and on it are these words, "Si monumentum requiris circumspice." To epitomize the life of a noted man is not an easy task. To remove the difficulty by entering upon a panegyric and an extension of details is less promising still. It remains, then, to carve a simple tablet by speaking briefly of his life and work, leaving to the good judgment and recollection of the reader the supreme prerogative of accurately filling in the details.

Alvan Graham Clark was born in Fall River, Mass., July 10, 1832, and died in Cambridgeport, June 9, 1897. His father, Alvan Clark, was born in Ashfield, Mass., March 8, 1804, and was a descendant of Thomas Clark, one of the early Pilgrim settlers. His mother was Maria (Pease) Clark. He had two sisters and one brother, George Bassett Clark, who was born in Lowell, February 14, 1827, and died in Cambridge, January 2, 1892.

The life of Alvan G. Clark is largely involved in the establishment and progress of the optical firm of which he was a member. His father, Alvan Clark, the founder of the firm, was originally a portrait painter, and early developed an unusual capacity for delicate manipulation. His attention was first called to lens making by an attempt of his son George to construct a telescope while a student at Andover. The books represented it as a very difficult thing. However, genius knows no limitations, and, without previous knowledge or discipline, the work was commenced and a telescope successfully made in the year 1846.

The work thus begun soon became a permanent occupation. Painting was exchanged for telescope making, and, about 1850, the house of Alvan Clark and Sons established. Both the sons inherited the father's skill, and entered into the work with him. Upon his death, the business was carried on by the sons together, and, upon the death of George, by Alvan alone.

Alvan Graham Clark was pre-eminently a self-made man. Inheriting to a remarkable degree the talents of his father, and with a fair amount of common school education, he carried lens making to the highest state of perfection the world has ever seen, so that a so called mechanical occupation was transferred to the realm of high art. But to make a good lens, good glass is necessary, and for a time the impossibility of obtaining good disks of large size seemed to present a barrier to the progress of telescope making. Fortunately this has been overcome in recent years by several European makers, notably by Feil of Paris and his successor Mantois, and it was upon this firm that Mr. Clark always relied.

In fact, disks sent by them were frequently rejected. Sometimes a lens would be nearly completed, and, with the gathering in of the last rays of light, a slight vein would be seen. Invariably the wellnigh completed lens was rejected and days of labor lost, for Mr. Clark would say, "I will keep up the standard of my work." As a result, the exquisite definition and clean cut images always confirmed the high standard of excellence set by the maker.

To make a lens is by no means an easy task. When one considers that not merely the chromatic and spherical aberration which relate to color and general figure proper have to be regarded, but also roundness, balance of figure, and several other considerations, it becomes evident that to construct a glass of the highest excellence is a very difficult task. To accomplish this, one must have not only a keen eye to see the defects, but good judgment and consummate skill to remove them without the incorporation of others.

One of the salient features of the Clarks' work was the method of local correction. This, although not wholly new in principle, was early adopted by them, and so extended and specialized that it has been called distinctively the Clark method. It reached its highest manifestation and refinement as used by the subject of this sketch, and may briefly be described as follows. After a lens has been ground with emery, it is polished with rouge on a bed of pitch or coal tar, the spherometer being frequently applied to see that it is approaching the desired curvature. But, although the spherometer will easily detect an irregularity of the fifty-thousandth of an inch, it is far too crude to satisfy the highest demands of science, so that recourse must be had to some other alternative, for even an irregularity of a few millionths of an inch must not be disregarded. It is here that the method of local correction comes in to remove the difficulty. The lens is now carried to the dark room and tested on an artificial star, the eye being placed at the focus. If the light is uniformly distributed over the whole surface and all the rays come to a sharp point, the lens is in good figure, but such a condition would be extremely rare. Portions of the surface will almost inevitably be brighter than others, indicating slight irregularities of curvature. These must be eliminated by returning the lens to the tool and removing the slight elevations by judicious polishing at these points. The lens must also be frequently inserted in the telescope tube and tested on an actual star at night. After this, the special local work begins. This consists in taking some rouge upon the finger and changing the curvature by delicate abrasion at those points which need correction, frequently testing the lens to see that the desired result is being obtained. Here the work is carried to millionths of an inch, for in a 6-inch lens of 90 inches focus, all the rays of light must be shot through a focal point $\frac{1}{2400}$ of an inch in diameter. By tests with the polariscope, however, it may be found that the glass is not quite homogeneous in density, though without any definite flaw. In such a case the curvature must be changed to obviate this condition, so that the best lenses are not always true curves. As an instance of the amount of labor involved in local correction and testing, it may be mentioned that the great Lick telescope of 36 inches diameter was removed to the yard with its attendant risk, attached to the great tube, and tried on stars on fifty-two different nights, beside all the testing in the dark room. It becomes evident, then, that to see the defects, judge correctly of their character, and remove them without incorporating others, demands the keenest eye, the most delicate judgment, and exquisite manipulation, and it was here that Mr. Clark stood unrivalled.

Among the principal telescopes of the Clarks, and to which the subject of this sketch contributed the benefit of his judgment and skill, may be mentioned one of 18¾ inches aperture for the Northwestern University, now located at Evanston, Ill. The next increase in size was marked by the construction of the Princeton refractor of 23 inches aperture. After this, a lens of 26 inches was made for the Naval Observatory at Washington, and one of about 26½ inches for the Leander McCormick Observatory of the University of Virginia. Then followed the 30-inch refractor for the Imperial Observatory at Pulkowa, for which a gold medal was awarded by the Russian government. Finally, as the last of the joint productions of the Clarks, came the famous Lick refractor of 36 inches aperture. It may be added that Mr. Alvan G. Clark did, practically, all the work on this lens, and brought it to its final perfection.

After the death of his brother George, he became sole manager of the firm. In this capacity he either made or superintended the construction of several great lenses, besides many smaller ones. These include the 20-inch lens for the Denver Observatory, one of 24 inches for Mr. Percival Lowell, the 24-inch Bruce Photographic telescope for the Harvard Observatory station at Arequipa, Peru, and, finally, as a crowning triumph, the great Yerkes lens of 40 inches in diameter.

This last he accompanied to its final destination, and superintended its mounting only a few days before his death. Beside his optical work, he was a member of several governmental eclipse expeditions, and also the discoverer of a number of close double stars. Nothing gave him more pleasure than the discovery of these difficult doubles, especially as they were all made with Clark glasses. One of his earliest and most important discoveries in this line was that of the companion of Sirius, in 1862, having been made in the yard adjoining the workshop with the newly constructed 18¾-inch lens before it was sent to Chicago. Turning on Sirius one evening, he detected something unusual, and shortly remarked that the star had a companion. This discovery, splendid enough in itself, was all the more so from the fact that, although irregularities in the motion of Sirius had been noticed and theorized upon, he knew nothing of them or of the predicted place of the companion. For this discovery, he received the Lalande Prize of the French Academy of Sciences.

He married, January 2, 1865, Mary Willard, daughter of Joseph Willard. She died on July 10, 1892. They had one son, Alvan, who died when a young man, and three daughters, still living.

In personal appearance and social intercourse Mr. Clark was unusually attractive. With finely cut features, of sympathetic nature and serene temper, he drew to himself a host of friends.

An hour at his workshop was an unusual pleasure, both for the scientific man as well as the ordinary individual, and no one was ever turned away.

His love for the best literature was intense. Shakespeare and the poets were his especial favorites, and, endowed with a remarkably retentive memory, he could quote from them almost indefinitely.

To him death was the inevitable sequel of life, the gate to be opened by a kind and all-wise Providence, and so without fear he met the future.

To make the most superb lenses, in which every slender ray of light shall be forced to bring its message of stellar history to a focal point, and to see these lenses steadily reach a size only considered possible with each successive achievement, — this was the ambition of Alvan Graham Clark, and in him it found complete fulfilment.

OLIVER C. WENDELL.

ALONZO SMITH KIMBALL.

DOCTOR ALONZO S. KIMBALL, who was for a quarter of a century Professor of Physics in the Worcester Polytechnic Institute, was born at Centre Harbor, New Hampshire, in 1843. He was prepared for college at New Hampton Academy, and was graduated from Amherst College in 1866. In 1871, he was called to the Worcester Polytechnic Institute, which had just graduated its first class. He organized the department of Physics, and the Institute was among the first in the country to provide systematic instruction in a physical laboratory. After seven or eight years of great activity and usefulness, shown alike in the development of the important department of which he had charge and in a series of valuable original contributions to physical science, he was, in 1879, attacked by a painful disease, which, in spite of the highest medical skill in both this country and Europe, proved to be incurable, and from the effects of which he died on December 2, 1897. Notwithstanding the steady progress of a malady which entailed nearly continuous suffering, Professor Kimball through all of these years discharged the constantly increasing duties of his position to the great satisfaction of the officers of the Institute and of his hundreds of pupils, to whom his life and work were always inspiring. In addition to his regular work in Worcester he was for several years a lecturer at Mount Holyoke College, of which institution he was also for many years and at the time of his death a trustee. While the Salisbury Laboratories of the Polytechnic Institute were being built, he spent a year in Europe, engaged in the study of the best European establishments, and in selecting apparatus for the better equipment of the new building to which his department was to be transferred. While there he suffered from a more than usually acute attack, and submitted to a difficult and dangerous surgical operation which it was hoped might lead to a permanent recovery. Only temporary relief followed, however, and within the past five or six years several similar operations were performed with the same result. His work in the lecture room and laboratory was not seriously interrupted, although carried on under conditions that would have made it impossible with most men. When, ten or fifteen years ago, the creation of a new branch of Engineering began, Professor Kimball was not slow to appreciate its importance, and the Institute was among the first schools of applied science to offer a course in Electricity, with ample equipment of electrical machinery and other appliances necessary to its success. The management and development of this course, along with the course in pure physics, remained with him until about two years ago, when its magnitude had increased so greatly that it became necessary to set off the Electrical Engineering as a separate department, with a special Professor at its head. With lessened responsibility, his enthusiasm and for a time his activity greatly increased, but his enjoyment of the new conditions was unfortunately of short duration.

Professor Kimball was uncommonly skilful in experiment, possessing originality in design, and his work was done with that sense of refinement and precision which is essential to original research. Between the years 1875 and 1880, he published in various scientific journals a series of papers, each the result of wisely planned and carefully conducted experiment, and all of much value. The first was on "Sliding Friction," published in the American Journal of Science, March, 1876. It marked the beginning of an important investigation of the general subject of friction, the results of which were published in subsequent numbers of the same journal, in Van Nostrand's Engineering Magazine, and elsewhere. In these papers he shows that friction between sliding surfaces is independent of neither velocity nor pressure, experiment pointing to the existence of a maximum coefficient of friction depending on both velocity and pressure. During these years there were also other papers on the influence of temper upon the physical properties of steel, the effect of magnetization on the physical properties of iron, etc. There was also prepared and printed a small treatise on Thermodynamics, arranged especially for the use of his pupils, exhibiting much originality and clearness in method of presentation. In later years occasional publications were made of original investigations, which he was able to undertake at intervals in spite of the progress of the disease from which he was continually suffering. Among these was one on the influence of magnetic stress upon the capacity of an electric condenser, published in the Proceedings of this Academy, Volume XXI., page 193.

From the quality of Professor Kimball's work during this period, there can be little doubt that he would have achieved marked distinction in his chosen field but for the failure of his health, which he never recovered. From 1879 to his death, a period of nearly twenty years, his fight was against odds that must long ago have defeated any one endowed with only the average human courage and tenacity of purpose. Conscientiously discharging every duty that the day brought, he had little energy left for research work, although he published occasional papers, and was always anxious to utilize any temporary increment of vitality in that way. Professor Kimball was elected a Fellow of the American Academy of Arts and Sciences on May 27, 1884, but, although a member of numerous scientific societies, he was rarely seen at their meetings, his long illness thus standing in the way of those intimate personal and social relations with his confreres for which he was by nature so admirably fitted. His manner was charming, his good nature unceasing, and his instincts were fine and noble.

To those with whom he was associated in work, or who were otherwise privileged to know him intimately, his prolonged but splendidly heroic struggle with a fatal disease, together with the uniformly high standard of performance which that struggle did not sensibly affect, will ever remain an inspiring example of the best of human qualities.

T. C. Mendenhall.

Other notices are unavoidably postponed.

Three Resident Fellows have resigned, one has been dropped, and the Academy has received an accession of nine Resident Fellows, six Associate Fellows, and eight Foreign Honorary Members.

The roll of the Academy, corrected to date, includes the names of 191 Resident Fellows, 96 Associate Fellows, and 66 Foreign Honorary Members.

Boston, May 11, 1898.

LIST
OF THE
FELLOWS AND FOREIGN HONORARY MEMBERS.

(Corrected to June 1, 1898.)

RESIDENT FELLOWS.—194.

(Number limited to two hundred.)

CLASS I.—*Mathematical and Physical Sciences.*—73.

SECTION I.—16.

Mathematics and Astronomy.

Solon I. Bailey,	Cambridge.
Seth C. Chandler,	Cambridge.
J. Rayner Edmands,	Cambridge.
Gustavus Hay,	Boston.
Henry Mitchell,	Nantucket.
James Mills Peirce,	Cambridge.
Edward C. Pickering,	Cambridge.
John Ritchie, Jr.,	Boston.
John D. Runkle,	Brookline.
T. H. Safford,	Williamstown.
Edwin F. Sawyer,	Brighton.
Arthur Searle,	Cambridge.
William E. Story,	Worcester.
Henry Taber,	Worcester.
O. C. Wendell,	Cambridge.
P. S. Yendell,	Dorchester.

SECTION II.—22.

Physics.

A. Graham Bell,	Washington.
Clarence J. Blake,	Boston.
Francis Blake,	Weston.
John H. Blake,	Boston.
Charles R. Cross,	Brookline.
Amos E. Dolbear,	Somerville.
H. M. Goodwin,	Boston.
Edwin H. Hall,	Cambridge.
Hammond V. Hayes,	Cambridge.
Silas W. Holman,	Boston.
William L. Hooper,	Somerville.
William W. Jacques,	Newton.
Frank A. Laws,	Boston.
T. C. Mendenhall,	Worcester.
Benjamin O. Peirce,	Cambridge.
A. Lawrence Rotch,	Boston.
Wallace C. Sabine,	Cambridge.
John S. Stone,	Boston.
Elihu Thomson,	Lynn.
John Trowbridge,	Cambridge.
A. G. Webster,	Worcester.
Robert W. Willson,	Cambridge.

SECTION III.—21.

Chemistry.

Samuel Cabot,	Boston.
Arthur M. Comey,	Cambridge.
Thos. M. Drown,	So. Bethlehem, Pa.
Charles W. Eliot,	Cambridge.
Thomas Gaffield,	Boston.

Henry B. Hill,	Cambridge.
Charles L. Jackson,	Cambridge.
Walter L. Jennings,	Worcester.
Leonard P. Kinnicutt,	Worcester.
Charles F. Mabery,	Cleveland, O.
Arthur Michael,	Boston.
George D. Moore,	Worcester.
Charles E. Munroe,	Washington.
John U. Nef,	Chicago.
Robert H. Richards,	Boston.
Theodore W. Richards,	Cambridge.
Charles R. Sanger,	St. Louis.
Stephen P. Sharples,	Cambridge.
Francis H. Storer,	Boston.
Charles H. Wing,	Ledger, N. C.
Edward S. Wood,	Boston.

SECTION IV. — 14.

Technology and Engineering.

Eliot C. Clarke,	Boston.
Ira N. Hollis,	Cambridge.
Gaetano Lanza,	Boston.
E. D. Leavitt,	Cambridgeport.
William R. Livermore,	Boston.
Hiram F. Mills,	Lowell.
Cecil H. Peabody,	Boston.
Alfred P. Rockwell,	Manchester.
Andrew H. Russell,	Rock Island, Ill.
Peter Schwamb,	Arlington.
Charles S. Storrow,	Boston.
George F. Swain,	Boston.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

CLASS II. — *Natural and Physiological Sciences.* — 63.

SECTION I. — 13.

Geology, Mineralogy, and Physics of the Globe.

H. H. Clayton,	Milton.
Algernon Coolidge,	Boston.
William O. Crosby,	Boston.
William M. Davis,	Cambridge.
Benj. K. Emerson,	Amherst.
O. W. Huntington,	Newport, R. I.
Robert T. Jackson,	Boston.
William H. Niles,	Cambridge.
John E. Pillsbury,	Boston.
Nathaniel S. Shaler,	Cambridge.
Warren Upham,	St. Paul, Minn.
Robert DeC. Ward,	Boston.
John E. Wolff,	Cambridge.

SECTION II. — 11.

Botany.

Geo. E. Davenport,	Medford.
William G. Farlow,	Cambridge.
Charles E. Faxon,	Boston.
George L. Goodale,	Cambridge.
H. H. Hunnewell,	Wellesley.
John G. Jack,	Boston.
B. L. Robinson,	Cambridge.
Charles S. Sargent,	Brookline.
Arthur B. Seymour,	Cambridge.
Charles J. Sprague,	Boston.
Roland Thaxter,	Cambridge.

SECTION III. — 24.

Zoölogy and Physiology.

Alexander Agassiz,	Cambridge.
Robert Amory,	Boston.
James M. Barnard,	Milton.
Henry P. Bowditch,	Boston.
William Brewster,	Cambridge.
Louis Cabot,	Brookline.
Samuel F. Clarke,	Williamstown.
W. T. Councilman,	Boston.
Charles B. Davenport,	Cambridge.
Harold C. Ernst,	Boston.
J. Walter Fewkes,	Washington, D.C.
Edward G. Gardiner,	Boston.
Samuel Henshaw,	Cambridge.
Alpheus Hyatt,	Cambridge.
John S. Kingsley,	Somerville.
Edward L. Mark,	Cambridge.
Charles S. Minot,	Boston.
Edward S. Morse,	Salem.

George H. Parker,	Cambridge.
James J. Putnam,	Boston.
Samuel H. Scudder,	Cambridge.
William T. Sedgwick,	Boston.
James C. White,	Boston.
William M. Woodworth,	Cambridge.

Section IV. — 15.

Medicine and Surgery.

Samuel L. Abbot,	Boston.
Edward H. Bradford,	Boston.
Arthur T. Cabot,	Boston.
David W. Cheever,	Boston.
Frank W. Draper,	Boston.
Thomas Dwight,	Boston.
Reginald H. Fitz,	Boston.
Charles F. Folsom,	Boston.
Frederick I. Knight,	Boston.
Francis Minot,	Hyde Park.
Samuel J. Mixter,	Boston.
W. L. Richardson,	Boston.
Theobald Smith,	Boston.
Henry P. Walcott,	Cambridge.
John C. Warren,	Boston.

Class III. — *Moral and Political Sciences.* — 58.

Section I. — 10.

Philosophy and Jurisprudence.

James B. Ames,	Cambridge.
Charles C. Everett,	Cambridge.
Horace Gray,	Boston.
John C. Gray,	Boston.
G. Stanley Hall,	Worcester.
Nathaniel Holmes,	Cambridge.
John E. Hudson,	Boston.
Francis C. Lowell,	Boston.
Josiah Royce,	Cambridge.
James B. Thayer,	Cambridge.

Section II. — 21.

Philology and Archæology.

William S. Appleton,	Boston.
Charles P. Bowditch,	Boston.
Lucien Carr,	Cambridge.
Franklin Carter,	Williamstown.
Joseph T. Clarke,	Boston.
Henry G. Denny,	Boston.
Epes S. Dixwell,	Cambridge.
William Everett,	Quincy.
William W. Goodwin,	Cambridge.
Henry W. Haynes,	Boston.
Charles R. Lanman,	Cambridge.
David G. Lyon,	Cambridge.
Bennett H. Nash,	Boston.
Frederick W. Putnam,	Cambridge.
Edward Robinson,	Boston.
F. B. Stephenson,	Boston.
Joseph H. Thayer,	Cambridge.
Crawford H. Toy,	Cambridge.
John W. White,	Cambridge.
John H. Wright,	Cambridge.
Edward J. Young,	Waltham.

Section III. — 15.

Political Economy and History.

Charles F. Adams,	Lincoln.
Edward Atkinson,	Boston.
Mellen Chamberlain,	Chelsea.
John Cummings,	Woburn.
Andrew M. Davis,	Cambridge.
Charles F. Dunbar,	Cambridge.
Samuel Eliot,	Boston.
John Fiske,	Cambridge.
A. C. Goodell,	Salem.
Henry C. Lodge,	Nahant.
A. Lawrence Lowell,	Boston.
Augustus Lowell,	Boston.
John C. Ropes,	Boston.
Denman W. Ross,	Cambridge.
Charles C. Smith,	Boston.

SECTION IV. — 12.

Literature and the Fine Arts.

Francis Bartlett,	Boston.
John Bartlett,	Cambridge.
George S. Boutwell,	Groton.
J. Elliot Cabot,	Brookline.
T. W. Higginson,	Cambridge.
George L. Kittredge,	Cambridge.
S. R. Koehler,	Boston.
Charles G. Loring,	Boston.
Percival Lowell,	Brookline.
Charles Eliot Norton,	Cambridge.
Horace E. Scudder,	Cambridge.
Barrett Wendell,	Boston.

ASSOCIATE FELLOWS.— 96.

(Number limited to one hundred. Elected as vacancies occur.)

CLASS I.—*Mathematical and Physical Sciences.*—34.

SECTION I.—14.

Mathematics and Astronomy.

Edward E. Barnard,	Chicago.
S. W. Burnham,	Chicago.
George Davidson,	San Francisco.
Fabian Franklin,	Baltimore.
Asaph Hall,	Cambridge.
George W. Hill,	Washington.
E. S. Holden,	Washington.
James E. Keeler,	Allegheny, Pa.
Emory McClintock,	New York.
Simon Newcomb,	Washington.
Charles L. Poor,	Baltimore.
George M. Searle,	Washington.
J. N. Stockwell,	Cleveland, O.
Chas. A. Young,	Princeton, N. J.

SECTION II.—6.

Physics.

Carl Barus,	Providence, R.I.
J. Willard Gibbs,	New Haven.
S. P. Langley,	Washington.
A. A. Michelson,	Chicago.
Ogden N. Rood,	New York.
H. A. Rowland,	Baltimore.

SECTION III.—7.

Chemistry.

Wolcott Gibbs,	Newport, R.I.
Frank A. Gooch,	New Haven.
S. W. Johnson,	New Haven.
J. W. Mallet,	Charlottesville, Va.
E. W. Morley,	Cleveland, O.
J. M. Ordway,	New Orleans.
Ira Remsen,	Baltimore.

SECTION IV.—7.

Technology and Engineering.

Henry L. Abbot,	New York.
Cyrus B. Comstock,	Washington.
W. P. Craighill,	Washington.
F. R. Hutton,	New York.
George S. Morison,	Chicago.
William Sellers,	Philadelphia.
Robt. S. Woodward,	New York.

CLASS II.—*Natural and Physiological Sciences.*—33.

SECTION I.—15.

Geology, Mineralogy, and Physics of the Globe.

Cleveland Abbe,	Washington.
George J. Brush,	New Haven.
Edward S. Dana,	New Haven.
Walter G. Davis,	Cordova, Arg.
Sir J. W. Dawson,	Montreal.
G. K. Gilbert,	Washington.
James Hall,	Albany, N.Y.
Clarence King,	New York.
Joseph LeConte,	Berkeley, Cal.
J. Peter Lesley,	Milton, Mass.
S. L. Penfield,	New Haven.
J. W. Powell,	Washington.
R. Pumpelly,	Newport, R.I.
A. R. C. Selwyn,	Ottawa.
G. C. Swallow,	Columbia, Mo.

SECTION II. — 5.

Botany.

D. H. Campbell,	Palo Alto, Cal.
A. W. Chapman,	Apalachicola, Fla.
J. M. Coulter,	Chicago.
W. Trelease,	St. Louis.
John D. Smith,	Baltimore.

SECTION III. — 6.

Zoölogy and Physiology.

Joel A. Allen,	New York.
W. K. Brooks,	Baltimore.
O. C. Marsh,	New Haven.
S. Weir Mitchell,	Philadelphia.
A. S. Packard,	Providence, R.I.
A. E. Verrill,	New Haven.

SECTION IV. — 7.

Medicine and Surgery.

John S. Billings,	New York.
Jacob M. Da Costa,	Philadelphia.
W. A. Hammond,	New York.
William Osler,	Baltimore.
Alfred Stillé,	Philadelphia.
Wm. H. Welch,	Baltimore.
H. C. Wood,	Philadelphia.

CLASS III. — *Moral and Political Sciences.* — 29.

SECTION I. — 6.

Philosophy and Jurisprudence.

James C. Carter,	New York.
T. M. Cooley,	Ann Arbor, Mich.
D. R. Goodwin,	Philadelphia.
Charles S. Peirce,	New York.
T. R. Pynchon,	Hartford, Conn.
Jeremiah Smith,	Cambridge.

SECTION II. — 7.

Philology and Archæology.

A. N. Arnold,	Pawtuxet, R.I.
Timothy Dwight,	New Haven.
B. L. Gildersleeve,	Baltimore.
D. C. Gilman,	Baltimore.
T. R. Lounsbury,	New Haven.
E. E. Salisbury,	New Haven.
A. D. White,	Ithaca, N.Y.

SECTION III. — 8.

Political Economy and History.

Henry Adams,	Washington.
G. P. Fisher,	New Haven.
M. F. Force,	Cincinnati.
H. E. von Holst,	Chicago.
Henry C. Lea,	Philadelphia.
Edward J. Phelps,	Burlington, Vt.
W. G. Sumner,	New Haven.
David A. Wells,	Norwich, Conn.

SECTION IV. — 8.

Literature and the Fine Arts.

James B. Angell,	Ann Arbor, Mich.
L. P. di Cesnola,	New York.
F. E. Church,	New York.
H. H. Furness,	Philadelphia.
R. S. Greenough,	Florence.
Augustus St. Gaudens,	New York.
E. C. Stedman,	Bronxville, N.Y.
W. R. Ware,	New York.

FOREIGN HONORARY MEMBERS.—66.

(Number limited to seventy-five. Elected as vacancies occur.)

CLASS I.—*Mathematical and Physical Sciences.*—20.

SECTION I.—7.

Mathematics and Astronomy.

Arthur Auwers,	Berlin.
George H. Darwin,	Cambridge.
H. A. E. A. Faye,	Paris.
Charles Hermite,	Paris.
William Huggins,	London.
Otto Struve,	Karlsruhe.
H. C. Vogel,	Potsdam.

SECTION II.—4.

Physics.

Ludwig Boltzmann,	Vienna.
A. Cornu,	Paris.
Lord Rayleigh,	Witham.
Sir G. G. Stokes, Bart.,	Cambridge.

SECTION III.—7.

Chemistry.

Adolf Baeyer,	Munich.
Marcellin Berthelot,	Paris.
Robert Bunsen,	Heidelberg.
J. H. van't Hoff,	Berlin.
D. Mendeleeff,	St. Petersburg.
Sir H. E. Roscoe,	London.
Julius Thomsen,	Copenhagen.

SECTION IV.—2.

Technology and Engineering.

Lord Kelvin,	Glasgow.
Maurice Lévy,	Paris.

CLASS II.—*Natural and Physiological Sciences.*—23.

SECTION I.—5.

Geology, Mineralogy, and Physics of the Globe.

Albert Heim,	Zurich.
A. E. Nordenskiöld,	Stockholm.
C. F. Rammelsberg,	Berlin.
Henry C. Sorby,	Sheffield.
Heinrich Wild,	Zurich.

SECTION II.—6.

Botany.

J. G. Agardh,	Lund.
E. Bornet,	Paris.
Sir Joseph D. Hooker,	Sunningdale.
W. Pfeffer,	Leipsic.
Solms-Laubach,	Strassburg.
Eduard Strasburger,	Bonn.

SECTION III. — 7.

Zoölogy and Physiology.

Michael Foster,	Cambridge.
Carl Gegenbauer,	Heidelberg.
Ludimar Hermann,	Königsberg.
Albrecht Kölliker,	Würzburg.
A. Kovalevsky,	St. Petersburg.
Lacaze-Duthiers,	Paris.
Elias Metschnikoff,	Paris.

SECTION IV. — 5.

Medicine and Surgery.

W. Kühne,	Heidelberg.
Lord Lister,	London.
Sir James Paget, Bart.,	London.
F. v. Recklinghausen,	Strassburg.
Rudolph Virchow,	Berlin.

CLASS III. — *Moral and Political Sciences.* — 23.

SECTION I. — 5.

Philosophy and Jurisprudence.

Heinrich Brunner,	Berlin.
F. W. Maitland,	Cambridge.
James Martineau,	London.
Sir Frederick Pollock,	Oxford.
Henry Sidgwick,	Cambridge.

SECTION II. — 7.

Philology and Archæology.

Ingram Bywater,	Oxford.
W. Dörpfeld,	Athens.
Sir John Evans,	Hemel Hempstead.
J. W. A. Kirchhoff,	Berlin.
G. C. C. Maspero,	Paris.
Max Müller,	Oxford.
Karl Weinhold,	Berlin.

SECTION III. — 5.

Political Economy and History.

Duc de Broglie,	Paris.
James Bryce,	Oxford.
Hermann Grimm,	Berlin.
Theodor Mommsen,	Berlin.
William Stubbs,	Oxford.

SECTION IV. — 6.

Literature and the Fine Arts.

Georg Brandes,	Copenhagen.
F. Brunetière,	Paris.
Jean Léon Gérôme,	Paris.
P. Puvis de Chavannes,	Paris.
John Ruskin,	Coniston.
Leslie Stephen,	London.

STATUTES AND STANDING VOTES.

STATUTES.

Adopted May 30, 1854: *amended September* 8, 1857, *November* 12, 1862, *May* 24, 1864, *November* 9, 1870, *May* 27, 1873, *January* 26, 1876, *June* 16, 1886, *October* 8, 1890, *January* 11 *and May* 10, 1893, *April* 11, *May* 9, *and October* 10, 1894, *and March* 13, *April* 10, *and May* 8, 1895.

CHAPTER I.

OF FELLOWS AND FOREIGN HONORARY MEMBERS.

1. The Academy consists of *Fellows* and *Foreign Honorary Members.* They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, viz.: Class I. The Mathematical and Physical Sciences; — Class II. The Natural and Physiological Sciences; — Class III. The Moral and Political Sciences. Each Class is divided into four Sections, viz.: Class I., Section 1. Mathematics and Astronomy; — Section 2. Physics; — Section 3. Chemistry; — Section 4. Technology and Engineering. Class II., Section 1. Geology, Mineralogy, and Physics of the Globe; — Section 2. Botany; — Section 3. Zoölogy and Physiology; — Section 4. Medicine and Surgery. Class III., Section 1. Philosophy and Jurisprudence; — Section 2. Philology and Archæology; — Section 3. Political Economy and History; — Section 4. Literature and the Fine Arts.

2. Fellows, resident in the State of Massachusetts, only, may vote at the meetings of the Academy.* Each Resident Fellow shall pay an admission fee of ten dollars and such annual assessment, not exceeding ten dollars, as shall be voted by the Academy at each Annual Meeting.

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* The number of Resident Fellows is limited by the Charter to 200.

3. Fellows residing out of the State of Massachusetts shall be known and distinguished as Associate Fellows. They shall not be liable to the payment of any fees or annual dues, but on removing within the State shall be admitted to the privileges,* and be subject to the obligations, of Resident Fellows. The number of Associate Fellows shall not exceed *one hundred*, of whom there shall not be more than *forty* in either of the three Classes of the Academy.

4. The number of Foreign Honorary Members shall not exceed *seventy-five;* and they shall be chosen from among persons most eminent in foreign countries for their discoveries and attainments in either of the three departments of knowledge above enumerated. And there shall not be more than *thirty* Foreign Members in either of these departments.

CHAPTER II.

OF OFFICERS.

1. There shall be a President, three Vice-Presidents, one for each Class, a Corresponding Secretary, a Recording Secretary, a Treasurer, and a Librarian, which officers shall be annually elected, by ballot, at the Annual Meeting, on the second Wednesday in May.

2. At the same time, and in the same manner, nine Councillors shall be elected, three from each Class of the Academy, but the same Fellows shall not be eligible on more than three successive years. These nine Councillors, with the President, the three Vice-Presidents, the two Secretaries, the Treasurer, and the Librarian, shall constitute the Council. It shall be the duty of this Council to exercise a discreet supervision over all nominations and elections. With the consent of the Fellow interested, they shall have power to make transfers between the several Sections of the same Class, reporting their action to the Academy.

3. If any office shall become vacant during the year, the vacancy shall be filled by a new election, and at the next stated meeting, or at a meeting called for this purpose.

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* Associate Fellows may attend, but cannot vote, at meetings of the Academy. See Chapter I. 2.

CHAPTER III.

OF NOMINATIONS OF OFFICERS.

1. At the stated meeting in March, the President shall appoint from the next retiring Councillors a Nominating Committee of three Fellows, one for each class.

2. It shall be the duty of this Nominating Committee to prepare a list of candidates for the offices of President, Vice-Presidents, Corresponding Secretary, Recording Secretary, Treasurer, Librarian, Councillors, and the Standing Committees which are chosen by ballot; and to cause this list to be sent by mail to all the Resident Fellows of the Academy not later than four weeks before the Annual Meeting.

3. Independent nominations for any office, signed by at least five Resident Fellows and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call for the Annual Meeting, which shall then be issued not later than one week before that meeting.

4. The Recording Secretary shall prepare for use, in voting at the Annual Meeting, a ballot containing the names of all persons nominated for office under the conditions given above.

5. When an office is to be filled at any other time than at the Annual Meeting, the President shall appoint a Nominating Committee, in accordance with the provisions of Section 1, which shall announce its nomination in the manner prescribed in Section 2 at least two weeks before the time of election. Independent nominations, signed by at least five Resident Fellows and received by the Recording Secretary not later than one week before the meeting for election, shall be inserted in the call for that meeting.

CHAPTER IV.

OF THE PRESIDENT.

1. It shall be the duty of the President, and, in his absence, of the senior Vice-President present, or next officer in order as above enumerated, to preside at the meetings of the Academy; to summon extraordinary meetings, upon any urgent occasion; and to execute or see to the execution of the Statutes of the

Academy. Length of continuous membership in the Academy shall determine the seniority of the Vice-Presidents.

2. The President, or, in his absence, the next officer as above enumerated, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct. Bills presented on account of the Library, or the Publications of the Academy, must be previously approved by the respective committees on these departments.

3. The President, or, in his absence, the next officer as above enumerated, shall nominate members to serve on the different committees of the Academy which are not chosen by ballot.

4. Any deed or writing to which the common seal is to be affixed shall be signed and sealed by the President, when thereto authorized by the Academy.

CHAPTER V.

OF STANDING COMMITTEES.

1. At the Annual Meeting there shall be chosen the following Standing Committees, to serve for the year ensuing, viz.: —

2. The Committee of Finance, to consist of the President, Treasurer, and one Fellow chosen by ballot, who shall have charge of the investment and management of the funds and trusts of the Academy. The general appropriations for the expenditures of the Academy shall be moved by this Committee at the Annual Meeting, and all special appropriations from the general and publication funds shall be referred to or proposed by this Committee.

3. The Rumford Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications and claims for the Rumford Premium, also on all appropriations from the income of the Rumford Fund, and generally see to the due and proper execution of this trust.

4. The C. M. Warren Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications for appropriations from the income of the C. M. Warren Fund, and generally see to the due and proper execution of this trust.

5. The Committee of Publication, of three Fellows, to whom all memoirs submitted to the Academy shall be referred, and to

whom the printing of memoirs accepted for publication shall be intrusted.

6. The Committee on the Library, of three Fellows, who shall examine the Library, and make an annual report on its condition and management.

7. An Auditing Committee, of two Fellows, for auditing the accounts of the Treasurer.

CHAPTER VI.

OF THE SECRETARIES.

1. The Corresponding Secretary shall conduct the correspondence of the Academy, recording or making an entry of all letters written in its name, and preserving on file all letters which are received; and at each meeting he shall present the letters which have been addressed to the Academy since the last meeting. With the advice and consent of the President, he may effect exchanges with other scientific associations, and also distribute copies of the publications of the Academy among the Associate Fellows and Foreign Honorary Members, as shall be deemed expedient; making a report of his proceedings at the Annual Meeting. Under the direction of the Council for Nomination, he shall keep a list of the Fellows, Associate Fellows, and Foreign Honorary Members, arranged in their Classes and in Sections in respect to the special sciences in which they are severally proficient; and he shall act as secretary to the Council.

2. The Recording Secretary shall have charge of the Charter and Statute-book, journals, and all literary papers belonging to the Academy. He shall record the proceedings of the Academy at its meetings; and after each meeting is duly opened, he shall read the record of the preceding meeting. He shall notify the meetings of the Academy, and apprise committees of their appointment. He shall post up in the Hall a list of the persons nominated for election into the Academy; and when any individual is chosen, he shall insert in the record the names of the Fellows by whom he was nominated.

3. The two Secretaries, with the Chairman of the Committee of Publication, shall have authority to publish such of the proceedings of the Academy as as may seem to them calculated to promote the interests of science.

CHAPTER VII.

OF THE TREASURER.

1. The Treasurer shall give such security for the trust reposed in him as the Academy shall require.

2. He shall receive officially all moneys due or payable, and all bequests or donations made to the Academy, and by order of the President or presiding officer shall pay such sums as the Academy may direct. He shall keep an account of all receipts and expenditures; shall submit his accounts to the Auditing Committee; and shall report the same at the expiration of his term of office.

3. The Treasurer shall keep a separate account of the income and appropriation of the Rumford Fund, and report the same annually.

4. All moneys which there shall not be present occasion to expend shall be invested by the Treasurer, under the direction of the Finance Committee, on such securities as the Academy shall direct.

CHAPTER VIII.

OF THE LIBRARIAN AND LIBRARY.

1. It shall be the duty of the Librarian to take charge of the books, to keep a correct catalogue of same, and to provide for the delivery of books from the Library. He shall also have the custody of the publications of the Academy.

2. The Librarian, in conjunction with the Committee on the Library, shall have authority to expend, as they may deem expedient, such sums as may be appropriated, either from the Rumford or the General Fund of the Academy, for the purchase of books, and for defraying other necessary expenses connected with the Library. They shall have authority to propose rules and regulations concerning the circulation, return, and safe-keeping of books; and to appoint such agents for these purposes as they may think necessary.

3. To all books in the Library procured from the income of the Rumford Fund, the Librarian shall cause a stamp or label to be affixed, expressing the fact that they were so procured.

4. Every person who takes a book from the Library shall give a receipt for the same to the Librarian or his assistant.

5. Every book shall be returned in good order, regard being had to the necessary wear of the book with good usage. And if any book shall be lost or injured, the person to whom it stands charged shall replace it by a new volume or set, if it belongs to a set, or pay the current price of the volume or set to the Librarian; and thereupon the remainder of the set, if the volume belonged to a set, shall be delivered to the person so paying for the same.

6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

CHAPTER IX.

Of Meetings.

1. There shall be annually four stated meetings of the Academy; namely, on the second Wednesday in May (the Annual Meeting), on the second Wednesday in October, on the second Wednesday in January, and on the second Wednesday in March. At these meetings only, or at meetings adjourned from these and regularly notified, shall appropriations of money be made, or alterations of the statutes or standing votes of the Academy be effected.

2. Fifteen Fellows shall constitute a quorum for the transaction of business at a stated meeting. Seven Fellows shall be sufficient to constitute a meeting for scientific communications and discussions.

3. The Recording Secretary shall notify the meetings of the Academy to each Fellow residing in Boston and the vicinity; and he may cause the meetings to be advertised, whenever he deems such further notice to be needful.

CHAPTER X.

OF THE ELECTION OF FELLOWS AND HONORARY MEMBERS.

1. Elections shall be made by ballot, and only at stated meetings.

2. Candidates for election as Resident Fellows must be proposed by two or more Resident Fellows, in a recommendation signed by them, specifying the Section to which the nomination is made, which recommendation shall be transmitted to the Corresponding Secretary, and by him referred to the Council for Nomination. No person recommended shall be reported by the Council as a candidate for election, unless he shall have received a written approval, signed at a meeting of the Council by at least seven of its members. All nominations thus approved shall be read to the Academy at a stated meeting, and shall then stand on the nomination list during the interval between two stated meetings, and until the balloting. No person shall be elected a Resident Fellow, unless he shall have been resident in this Commonwealth one year next preceding his election. If any person elected a Resident Fellow shall neglect for one year to pay his admission fee, his election shall be void; and if any Resident Fellow shall neglect to pay his annual assessments for two years, provided that his attention shall have been called to this article, he shall be deemed to have abandoned his Fellowship; but it shall be in the power of the Treasurer, with the consent of the Council, to dispense (*sub silentio*) with the payment both of the admission fee and of the assessments, whenever in any special instance he shall think it advisable so to do.

3. The nomination of Associate Fellows shall take place in the manner prescribed in reference to Resident Fellows; and after such nomination shall have been publicly read at a stated meeting previous to that when the balloting takes place, it shall be referred to the Council for Nomination; and a written approval, authorized and signed at a meeting of said Council by at least seven of its members, shall be requisite to entitle the candidate to be balloted for. The Council may in like manner originate nominations of Associate Fellows, which must be read at a stated meeting previous to the election, and be exposed on the nomination list during the interval.

4. Foreign Honorary Members shall be chosen only after a nomination made at a meeting of the Council, signed at the time by at least seven of its members, and read at a stated meeting previous to that on which the balloting takes place.

5. Three fourths of the ballots cast must be affirmative, and the number of affirmative ballots must amount to eleven to effect an election of Fellows or Foreign Honorary Members.

6. Each Section of the Academy is empowered to present lists of persons deemed best qualified to fill vacancies occurring in the number of Foreign Honorary Members or Associate Fellows allotted to it; and such lists, after being read at a stated meeting, shall be referred to the Council for Nomination.

7. If, in the opinion of a majority of the entire Council, any Fellow — Resident or Associate — shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his Fellowship; and provided that a majority of two thirds of the Fellows at a stated meeting, consisting of not less than fifty Fellows, shall adopt this recommendation, his name shall be stricken off the roll of Fellows.

CHAPTER XI.

OF AMENDMENTS OF THE STATUTES.

1. All proposed alterations of the Statutes, or additions to them, shall be referred to a committee, and, on their report at a subsequent meeting, shall require for enactment a majority of two thirds of the members present, and at least eighteen affirmative votes.

2. Standing Votes may be passed, amended, or rescinded, at any stated meeting, by a majority of two thirds of the members present. They may be suspended by a unanimous vote.

CHAPTER XII.

OF LITERARY PERFORMANCES.

1. The Academy will not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its publications.

STANDING VOTES.

1. Communications of which notice had been given to the Secretary shall take precedence of those not so notified.

2. Resident Fellows who have paid all fees and dues chargeable to them are entitled to receive one copy of each volume or article printed by the Academy, on application to the Librarian personally or by written order, within two years from the date of publication. And the current issues of the Proceedings shall be supplied, when ready for publication, free of charge, to all the Fellows and members of the Academy who desire to receive them.

3. The Committee of Publication shall fix from time to time the price at which the publications of the Academy may be sold. But members may be supplied at half this price with volumes which they are not entitled to receive free, and which are needed to complete their sets.

4. Two hundred extra copies of each paper accepted for publication in the Memoirs or Proceedings of the Academy shall be placed at the disposal of the author, free of charge.

5. Resident Fellows may borrow and have out from the Library six volumes at any one time, and may retain the same for three months, and no longer.

6. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

7. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy, except by special leave of the Librarian.

8. Books, publications, or apparatus shall be procured from the income of the Rumford Fund only on the certificate of the Rumford Committee that they, in their opinion, will best facilitate and encourage the making of discoveries and improvements which may merit the Rumford Premium.

9. The Annual Meeting and the other stated meetings shall be holden at eight o'clock, P. M.

10. A meeting for receiving and discussing scientific communications may be held on the second Wednesday of each month not appointed for stated meetings, excepting July, August, and September.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Benjamin, Count Rumford, granting a certain fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of said fund, as it now exists, at any Annual Meeting, an award of a gold and silver medal, being together of the intrinsic value of three hundred dollars, as a premium to the author of any important discovery or useful improvement in light or in heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference being always given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind; and to add to such medals, as a further premium for such discovery and improvement, if the Academy see fit so to do, a sum of money not exceeding three hundred dollars.

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